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# Production Methodology for the Validation of Electronic Fuzes


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The primary objective of this study was to evaluate the concept of validating the producibility of equipment during its development by use of prototype fabrication. Discussions in this report include the semiconductor and thick film areas as well as printed circuit electronic and environmental testing. Also discussed are mechanical fabrication, computer support technology, and fuze assembly equipment and techniques. The equipment and facility requirements are presented, operating procedures and costs are enumerated, and a five-year plan for implementation of this facility is presented.


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## Executive Summary

by John J Furlani

### 1. Introduction

In perusing this report, the reader must remain aware of the fact that the bulk of the material presented herein was originally written in 1976 Except for minor technical, editorial, and manuscript preparation changes, the chapter contents represent the thinking and predictions of the chapter authors at the concept planning stage of the Prototype Validation Facility (PVF). It is quite gratifying to the authors that so many of the ideas, innovations, and applications eventually worked themselves into the actual architectural design plans and functional criteria for the PVF

Considerable support was found and a major effort was expended in bringing this project through the many steps of the Military Construction Army (MCA) program Approval for this line item, entitled Research and Engineering Support Annex (RESA), was received up to the level of the Office of the Secretary of Defense, and it was included in the FY79 and -80 MCA budgets The level of approval resulted in the Corps of Engineers awarding 35-percent funding for architectural concept design. Unfortunately, in each fiscal year, economic restraints and demands of programs having higher priority deferred the start of construction At this time, the project has been deleted from the MCA listing, and its future is uncertain

To a large extent, the effort required for updating the PVF design, presentation, and documentation took precedence over issuance of this report Additionally, the hope that authors would update their chapters and put them into a more polished state was never fully achieved This situation was somewhat expected, since funding had been expended and higher priority demands almost always existed for all personnel involved in the report

Nevertheless, this report is now being issued to complete project commitments and to serve as a record of the conceptual thinking that went into the design of the PVF The concept, incorporating production methods into prototype design and validation, is still viable Even though the concept will not now be carried out in a thorough, formalized manner in a dedicated facility, the authors are confident that the ordnance community is aware of the problem and will, as much as possible, consider and incorporate production-compatible materials, methods, and designs into the prototype development phase.

### 2. Historical Background

The Harry Diamond Laboratories (HDL) has been developing electronic fuzes since World War II, when the Laboratories were the Ordnance Divisions of the National Bureau of Standards (NBS). It was there that the first proximity fuzes were invented. The fuze concepts, early designs, prototypes, and tests were done in-house, and contracts were then awarded to private industry for product engineering and initial production These contracts were then managed by a small group of laboratory people who had been involved in development of the fuze design. This method of operation was quite successful and remained the laboratory operational policy through the following years

In the 1950's, the ordnance functions of NBS laboratories were transferred to the Army and these laboratories became the Diamond Ordnance Fuze Laboratories (the forerunner of Harry Diamond Laboratories, so named to honor the inventor of the proximity fuze) An Industrial Division was established to oversee aspects of post-development fuze production The engineering staff in this Division was not a part of any research and development (R&D) activities They prepared the Technical Data Package (TDP), which was the documentation that included drawings and specifications of the fuze to be produced by industry. This Division was also involved in product improvement and production support—services that were obtained by contracts to private industry



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In the late 1950's, certain shortcomings in the division of responsibilities between the R&D and technical activities were evident: scarce engineering talent was squandered by duplication of effort, the life cycle of the fuzes (from invention to production) was lengthened because of (necessary) relearning when the fuze project moved from R&D into Industrial Engineering (IE), and probably the most serious shortcoming was the occurrence of the factor called "NIH" (not invented here). This factor accounted for the impossibility of pinpointing responsibility and explaining field performance deficiencies. The R&D people would say (correctly) that the fuze was working properly when they completed their phase. The IE people claimed (correctly) that the design, as given to them, had to be redone before the fuze could be manufactured. The contractor would say (correctly) that the end item was produced in keeping with the requirements of the TDP.

To remedy this grievous situation, the operation was reorganized. The Engineering and Product Assurance Division was made the responsible Commodity Manager, directing industrial engineering activities. The technical people responsible for engineering were located in various laboratories. After completion of the R&D phases, these laboratory people would "change hats," so to speak, and would report to the Engineering and Product Assurance Division as contract monitors. The complete procedure follows.

Concept design, fabrication of early prototypes, and testing to prove feasibility were continued in-house. At that stage, development contracts were awarded for the design to be engineered for production and for development quantities to be fabricated. The tests of these units continued through what has come to be known as the DT-1 (developmental testing) and DT-2 phases and, finally, through Type Classification (TC). Concurrently with development and testing, the contractor prepared the drawings, specifications, and inspection equipment data that became part of the TDP.

After TC, the "first buy" (a small-quantity procurement) was handled by the Industrial Division, which subcontracted the technical support to the project group in the development laboratories. It was at this time that engineering for production activities was conducted, if necessary. This procedure has continued, essentially unchanged, to the present time.

It became apparent that because of time constraints and limited funds, engineering for production could not ensure that the fuze would be designed for manufacture at the lowest cost on a production line. In addition, the process was inefficient, since the in-house project group performing the development was not well versed in production methods. The situation was further complicated by the fact that industrial contractors were not sensitive to the demands imposed by development engineering.

In most cases the fuze under development was intended to provide an advancement in the state of the art. Thus, it contained components and assemblies that were relatively unique and had not been manufactured previously, since a sponsor could justify funding support only if significant performance gains could be realized. As a result, new manufacturing approaches had to be developed or established processes had to be modified. More often than not, unfortunately, manufacturing methods for production occurred after development was completed and production was already underway. Many development programs were also adversely affected by the urgent need to manufacture large quantities of fuzes for delivery to the field. This was especially true during the Korean and Southeast Asia conflicts, although it continued through the "cold war." Concurrently, much concern was expressed by sponsors as well as by the laboratory command about the high cost of proximity fuzes and their cost-effectiveness compared to more conventional fuzes. Performance characteristics such as weapon effectiveness, functional reliability, and safety were spotlighted in relation to the cost of the fuze. Performance levels that were acceptable when the fuze cost \$15 to \$20 could not be justified when the fuze cost \$30 to \$40. It is now clear that the situation was not as serious as it seemed, because (1) there was a requirement for

more stringent performance that included a quantum increase in safety and made the fuze more complex and costly and (2) inflation was increasing the cost at a rate higher than in the past

## 3. Alternative Operating Methods

It was obvious to many people that if we were to reverse the rising trend in fuze costs, some changes in our operating methods were essential The most obvious solutions dealt with rising labor costs and the use of mechanization or automation to reduce those costs Programs like the 40-mm proximity fuze project during the Southeast Asia conflict advanced the concept of developing the automated production line in parallel with the fuze development This meant tailoring the production machines and tooling to the fuze design, thus compressing the development and industrial phases This approach offered not only low production costs but also a reduction in the time required to go from concept to production A major consideration of this type of approach is that it presents a higher risk than the past conventional approach, since a large expenditure is required for tooling even before the fuze design has been thoroughly proven Actually, however, it may be a general corollary that to make substantial savings in production costs, higher initial risk is necessary Another factor to be understood is that flexibility in the use of the equipment is limited and it is thus cost-effective only when large quantities are to be purchased

Nevertheless, the approach did gain acceptance [illegible] reduce production costs, several fuze programs introduced design of the manufacturing equipment for the fuze during the early stages of the fuze development life cycle rather than after the industrial phase was reached An immediate reaction to this statement might be that this is obviously a good idea that should be universally accepted In fact, one might go even further and charge that unless this procedure was followed all along, money was wasted The fact is, however, that developmental fuze projects have been funded and scheduled in a way that prevented manufacturing a low-cost, mass-producible end item

## 4. Organizational Limitations

One can imagine that developmental engineers are experts in current production technology and that this expertise can be applied to design fuzes that can be mass produced at minimal cost. In reality, HDL has very few production-type machines for experimental production engineering As a result, more reliance for production support was placed on skilled machinists and technicians Their experience included fabricating metal parts and electronic assemblies to the requirements of the drawings The machinists and technicians know first hand exactly how close tolerances can be held on the different machine tools, and they are aware of the time required and the difficulty involved in performing mechanical and assembly operations However, even this knowledge is insufficient since they lack the experience of working directly with production equipment

## 5. Philosophical Aspects

Assuming that producibility should be designed into our fuzes early in the cycle, how should it be implemented? Should HDL hire production engineers to design its fuzes? Should HDL send its development engineers to industry for on-the-job training? Should HDL realign its staffing of development projects by assigning cost engineers to the project groups? All these actions would help and would not cost very much to implement. But where are production engineers to be found who have experience in fuze development? It takes several years to train competent fuze engineers and designers Like a fuze development engineer, a production engineer becomes proficient by working in his field, and he stays proficient by continuing to work with the tools of his profession, which include current production equipment Whether HDL hires production engineers or develops them through training, they maintain their competence and productivity by testing their theoretical knowledge against the reality of producing parts on production machines, just as is done in the manufacturing industry. The state of the art in production technology, particularly in the electronics area, is changing

very rapidly How do we maintain the competence and awareness of these production engineers? How long a training period would be required for our development engineers to become effective in applying their new knowledge to fuze designs? And how do we maintain their competence and currentness? Would a cost engineer contribute to progress in the fuze engineer's work or further complicate the problem? These and other questions were considered during the course of this study and were used as guidelines to help in determining the conclusions that resulted

# Chapter I. The Electronic Fuze Prototype Validation Facility

by Frank L. Tevelow

As a result of many years' experience with several projects, a need was recognized for an improvement in the method of incorporating production technology as early as possible in the development phase of a fuze project in order to reduce production costs and overall time from conception to field implementation One possible method to achieve these objectives was to fabricate prototypes during the development phase using production equipment so that verification of performance and producibility could be achieved before the device was type classified and released to industry for large-scale production To determine whether this new approach was achievable, it was proposed that a study be conducted

This report summarizes the activities of the Production Engineering Measures (PEM) project No 5753077, initiated in June 1974. This project is a Manufacturing Methods and Technology (MM&T) engineering effort to define the Prototype Validation Facility (PVF) for electronic fuzes The proposed objectives of the study were to include the following

(a) identify the various manufacturing technologies available within the U S industry complex for the production of electronic fuzes and the specific capability of each of the technologies in terms of the established requirements for national mobilization

(b) Forecast the advancement of each of these technologies within the next 5 to 10 years

(c) Select the single most promising technology for Army electronic and proximity fuzing

(d) Study the various methods of production encompassed within the selected technology, including examination of the relative merits and disadvantages of each, and select one production method

(e) Develop technical performance specifications for such equipment as may be required for the selected production method

(f) Enumerate the exact quantities of each of the several types of production equipment that will be required for the prototype facility.

(g) Study the geographical location of the facility, considering such alternatives as Government operation and contractor operation

(h) Develop a floor plan for the facility.

(i) Estimate all cost data that will be required in support of a budget request for APA 4911 funding in subsequent years

(j) Define fast-response acceptance inspection equipment for both electrical and mechanical measurements, considering inclusion of transducers for automatic rejection of a defective fuze or fuze component and for automatic data recording when desirable

The PVF concept and function may be described quite definitively, although the role, scope, and limitations of the PVF require discussion and answers to questions on staffing, funding, projected use, and other considerations described in the scope of this study. The concept and function of the PVF, very simply, is to introduce production-type design and fabrication methods into the fuze design during the development phase and to validate this design by a "sample size" run and test before release of any large-size procurement contract

The concept of a PVF extends back many years at the Harry Diamond Laboratories (HDL) as a result of our long, committed involvement, contributions, and experience in the various fuze programs that had their start at HDL with the invention of the proximity fuze by Harry Diamond in 1942

Many advances have been made since then, with marked changes occurring as a result of advancing technologies in microminiaturization, solid-state components, and high energy, low-volume power supplies; the use of printed circuits, and high-density packaging methods These advances have both pointed up and given rise to various deficiencies in and impediments to the fuze development process existing now and, if not changed, expected to become more severe in the future The two major, across-the-board problem areas for almost all subsystems in fuze development are (1) the high cost and, in some instances, total inability to obtain ordnance-related components and subsystems from the commercial market and (2) the high cost and extended delays that have occurred in bringing a laboratory-designed and -validated fuze into production The first difficulty occurs since a research and development (R&D) program uses small numbers of components that even when available commercially, are high in cost A product, to be profitable, must today be "machine-intensive" (low net man-hours/item). A commercial market must thus be assured or the item is either unavailable or can be obtained only through special tooling at exorbitant cost

The second problem area is related to the first but occurs primarily because fabrication practices during the R&D phases of fuze design differ from those used in production A simple example is the machining of an item, rather than punching or casting as would be done in production In addition, a design or parts that can be manually assembled during R&D may not be practical for automated production Although refined engineering practice can compensate for these differences somewhat, a truly reliable, tested, and validated design can be obtained only by introduction of production-type design and fabrication during the prototype design phase In addition, a sample size run must be made on production-type equipment, and the fuze design and producibility must be validated before the release of any major contract These deficiencies are recognized and acknowledged universally—the problem thus becomes one of resolution

In 1968, HDL proposed a PVF that would involve the fuze designer and introduce production-line designs and fabrication methods into the R&D fuze development phase Basically, this would require setting up or adding to specific technology areas and the acquisition and installation of production-type fabrication machines, technologies, and assembly lines at HDL As described, this type of effort has a high initial cost and, similarly, large annual operational costs However, the specific costs cannot be determined until the various functions, operations, personnel requirements, machines, test equipment, etc , are defined and specified

Answers to these questions and, more specifically, to those outlined in the scope of the study, were to be achieved by canvassing of the various HDL laboratories and divisions involved with electronic fuze development A written report was requested containing information and comments on deficiencies, operations, personnel, equipment, and required funding that would beneficially and economically justify inclusion of their function within the concept of the PVF. Although the major divisions of an electronic fuze are identified as four subassemblies—the electronic head, the power supply, the electronic timer, and the safety and arming unit, positive responses have been received and will be presented in the following chapters according to technological divisions or operations Each chapter describes the facility and its operation as part of the PVF, equipment considerations, foreseeable technology changes and possible effects on equipment requirements and operations, and the alternatives or repercussions if their operation were not included in the PVF

The several technology chapters are reviewed and tied together in Chapter XII, Planning and Progress This chapter introduces and discusses problems relating to the role of the PVF as part of the Defense establishment and its policies, the desirability of Government operation over quasi-government or private industry operations, the desirability of a centralized PVF over a satellite system, the spin-off functions of the PVF, and conclusions and recommendations.

## Chapter II. Electromechanical Devices

by David L Overman, Robert N Johnson, and Roland A Ebner

### II-1. Background and Introduction

Most of the electromagnetic (EM) devices developed by HDL for electronic fuzes are small assemblies of mechanical electrical, and explosive components designed for high-volume production at low cost Typical EM devices are safety and arming mechanisms, power supply initiators, fluidic generators, turbine alternators, spin switches, and components containing electroexplosive actuators and detonators "Small" is generally less than 2 in (about 51 mm) in any dimension; "high volume" is greater than 50,000 per month, and "low cost" is in the range of $1 00 to $5.00 each Such designs must use low-cost fabrication techniques (stamping, coining, casting, sintering, and molding) in combination with mechanized assembly and testing in order to meet these volume and price goals

Typical past practice in the development of EM devices has been to build the small developmental quantities with heavy emphasis on conventional machining of the components from bar stock The machines were widely available and easy to use, also, design changes could be made inexpensively Once a new design was developed, it was turned over to a contractor experienced in high-volume production techniques, to be production engineered During this phase, many new problems usually developed and had to be resolved, creating additional expense and delay. These difficulties tended to be associated with changes in materials, processes, and assembly methods For example, die-cast parts came out with different tolerances and surface properties than the machined parts Sintered parts had different weights and density distributions, while molded parts tended to warp and shrink Some designs could not be assembled or tested with the automatic equipment Slight design changes needed to accommodate or take advantage of the production processes or techniques would have unforeseen consequences, often making it necessary to repeat the full spectrum of development tests on the production-engineered items

As Government designers worked with contractors to resolve these problems they became conscious of ways in which their initial designs could be improved to avoid subsequent production difficulties The situation was also improved by incorporating parts made by high-volume processes into the early development models whenever possible and by considering the consequences of assembly and testing by automatic machine early in the design phase

The current problem faced by the designer is the long lead time and expense required to procure small developmental quantities of, for example, die-cast metal parts It is either very costly or very difficult to locate outside vendors who are willing to go to the trouble to tool up for a part that may never go beyond the development stage. It is also very difficult to efficiently design die-cast, sintered molded, or stamped parts without having first-hand experience (or direct access to someone with first-hand experience) in building and operating the dies or molds In adapting to mechanized assembly and inspection, first-hand experience is again necessary to help avoid costly mistakes and to maximize the advantages to be gained by such equipment

### II-2. Recommended Equipment

Based on knowledge of HDL's current capabilities in EM devices, it is recommended that equipment of two types be purchased, set up, and operated within the scope of the proposed PVF. The first type is general-purpose shop equipment that would give HDL the ability to fabricate mechanical components in prototype quantities using the techniques that would normally be used for

these components in high-volume production The second category is general-purpose equipment for use in developing and evaluating new or improved techniques of mechanized assembly, testing, and inspection of EM devices Four general-purpose items are suggested for initial expansion of the shop fabrication facilities They are

(a) small die-casting machine(s) with the capacity of 1.5 oz per shot of aluminum and 4 oz per shot of zinc (about 33 g aluminum and 113 g zinc),

(b) small plastic molding machine especially designed for insert moldings, such as switch contact assemblies up to 0 1 in $^3$ (about 1 6 cm$^3$),

(c) small powder metal press and sintering furnace having a capacity for 2-oz pressings in b ass (about 57 g brass), and

(d) small, high-cycle-rate (50 strokes per minute typical) punch press of about a 3-ton capacity, capable of progressive stamping and forming operations.

Several other high-volume production processes such as thread rolling, cold heading, and fine-edge blanking might be considered for future expansion of the general shop portion of the PVF

Small machine size in the above descriptions means roughly 100 ft$^3$ of space This is an adequately sized machine for development work, whereas larger equipment would be a disadvantage Since these four items will be included in the general shop facilities section of the proposed PVF, they will not be considered further in this chapter However, the diemakers and machine operators for this equipment would be expected to become experts in their respective fields. As such, they would form the in-house consultant group for design guidance on high volume mechanical fabrication processes

In addition to the four high-production process machines recommended above, consideration should also be given to including necessary auxiliary equipment, specifically, deburring facilities for cast and stamped parts, and plating facilities for all metal parts Several deburring methods are consistent with high-volume operations This includes wet abrasive blasting, abrasive flow deburring, chemical deburring, thermal energy deburring, harperizing, and chemically a celerated vibratory deburring as referenced in the Selected Bibliography at the end of this chapter. The most important plating processes would be electroless nickel and chemical conversion coatings. Expertise and capabilities in these areas are expected to be general shop support functions, so that completely finished parts could be delivered to the assembly areas.

The following list suggests items of equipment for general-purpose use in the area of mechanized assembly and testing of EM devices.

(a) Two systems, each comprising a rotary synchronous indexing machine with a 36-in (914-mm) diameter dial, 24 stations, a size of approximately 4 × 6 × 7 ft (1 2 × 1.8 × 2.1 m), a self-contained pneumatic system, and all necessary logic and control systems

(b) A nonsynchronous (NS) transport system for input and output interfacing with the two synchronous machines

(c) A series of general-purpose or standard tooling modules for tooling the synchronous machines This includes, but is not limited to, an automatic spring winder, orbital and radial cold-forming and riveting heads, adjustable pick-and-place modules, punches, presses, presence, position, and force-sensing probes, markers, standard tool holders, soldering and welding he. ultrasonic head, vibratory feeders, tape blankers, metering heads for lubricant, sealant, and adhesives, and automatic screwdrivers

## II-3. Description of Facility

### *II-3.1 Layout*

The synchronous index machines and NS transport are arranged in a minimum-sized EM device automation laboratory facility, as illustrated by figure II-1 By coupling the equipment in

the manner shown, it would be possible to develop experience with both synchronous and NS automation operations in the same facility This is important because fuze contractors do use both types of equipment and they are quite different in their performance characteristics. Each has its peculiar advantages and disadvantages, and the plan would be to try to combine and take advantage of the best features of both types

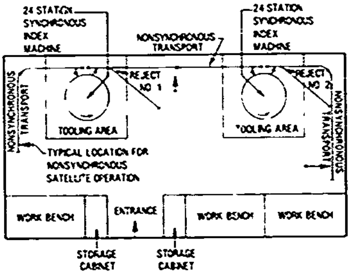


**Figure II-1. Electromechanical devices automation laboratory for Prototype Validation Facility.**

The transport system (4)* would have a belt or chain drive, guidance trackage, provision for slippage as the pallets pile up and come to a stop, escapements to release one pallet at a time to the pick-and-place unit or positioning and clamping mechanism, deflecting or switching devices for rejecting or sorting pallets, and possibly a pallet return system The pallets would have a memory system so that a faulty item in an intermediate stage of completion is flagged to preclude additional operations from being performed and to provide for rejection at the appropriate location in the cycle. Subpallets might also be designed to function as removable nests on the rotary worktable of the synchronous machines

**Numbers in parentheses refer to sources of automating equipment listed in appendix II-A, following this chapter*

### *II-3.2 Synchronous versus NS Operation*

Typical synchronous machines (5,6) have a rotating worktable from 1 to 6 ft (0 3048 to 1 8 m) in diameter that is indexed in 8 to 36 steps at 10 to 50 cycles per minute The work is positioned in nests on the table, and various operations (pick-and-place, orient, probe, test, etc ) are done by accessory tooling moving synchronously with the index mechanism. Operations performed at each station are kept relatively simple because of the high cycle rate and the need to minimize malfunctions Although a given machine may have 24 stations, the number of operations performed is most likely to be 6 to 12 in order to provide room for tooling and to minimize the capability lost if single stations malfunction Some synchronous machines are configured for an in-line transfer arrangement using pallets and a conveyor belt rather than the rotary indexed worktable (7)

Typical NS machine systems (8, 9, 10, 11) consist of a series of tooled stations connected by a transport system that feeds work pallets into and away from each station on demand. One to four operations are usually performed on the work at each station and the cycle rate is about 3 to 15 per minute.

The characteristic feature of an NS system is the storage capacity or "float" of pallets contained on the transport that allows each station to work independently (or to malfunction independently) of all other stations

It is difficult to build a case in favor of one type of machine over another, both synchronous and NS types are widely and successfully used by industry. Often the preference for a particular type is based on past experience and vested interest Any company with 10 years of productive experience with a given system will have developed the expertise to make it the system preferred by them and they will defend their choice strongly

Rotary synchronous machines are most often employed for machining, assembling, and testing smaller items such as safety and arming (S&A)

devices or switches. NS machines are most often employed for operations on larger items, such as loading/assembling/packing of artillery projectiles or manufacturing large automotive components However, NS machines are also being used to assemble small mechanisms such as alarm clocks and cameras

For the same job performance, a synchronous assembly system would generally be smaller (using less floor space) and cheaper than an NS system This difference is primarily due to the 5- to 8-ft (1.5 to 2.4 m) quay on the transport system between stations and the redundant power and control systems needed at each station on the NS system. Intermediate storage for the synchronous system is provided by bins of parts in bulk or by automatically loaded and unloaded racks of magazines The more compact nature of the synchronous system would be an advantage for one proposed use, i e., developing tooled machines (to perform particularly difficult operations such as a final S&A device test system) for shipment of the machine (tester) to the contractor who manufactures the item. Less tear down, shipping volume, and set up would be required.

Machine efficiency or availability (useful operating time) is another important item of comparison. This could be defined as the average number of products delivered per hour integrated on a monthly basis, divided by the basic cyclic rate of the machine Thus, the term machine efficiency includes the effects of stoppages, malfunctions, and maintenance on production totals Malfunctions on a synchronous machine stop the work at all stations, whereas on an NS system, only a single station is affected for disturbances of short duration Although the synchronous system may be instrinsically less efficient, it is generally accompanied by more highly refined tooling and requires more skill in designing, setting up, and operating than necessary with the NS machine. Also, because they are smaller, simpler, and cheaper, there is often more than one synchronous machine doing the same job in a complete system Proof of equivalent operating efficiencies is demonstrated by the large number of highly productive and competitive synchronous systems used throughout industry. Obviously there is a limit to the number of synchronous operations that can be performed efficiently at the same machine, this number is about 6 to 12. Therefore, a complete system is generally made up of a series of synchronous machines linked with a manual or automated NS transport system. (Thus, it might be more appropriately termed a semisynchronous system )

High-quality feed parts, standard for ordnance devices, are another help in achieving effective use of automated assembly machines. Although this would be a cost disadvantage for consumer products, it is not the most important consideration for military EM devices In order to simultaneously achieve the high degree of safety (one failure in 2.5 million) and reliability (greater than 99 percent) in a device that has only one chance to operate after a possible 20-yr storage period and unpredictable environmental stress, high-quality parts are required no matter how they are to be assembled

NS systems are said to be easier to set up, debug, and service than synchronous machines, but this is debatable The NS system can be expanded one station at a time, which makes debugging easier. However, total time spent setting up and debugging a 10-operation system (three or four stations versus one rotary index machine) might be greater for the NS system. The added space required for the NS transport system does provide better access for service or manual takeover of a malfunctioning station, but the multiplicity of power and control systems means more parts and potentially more servicing

Although both systems can use memory devices on the pallets or nests so that a faulty item can be tagged (as discussed in II-3.1), only the synchronous system can remember faulty items or empty nests electrically. The flexibility of modifying a given system to change or add unplanned operations is about the same for both because the synchronous system is generally not used at full capacity

### II-3.3 Typical Synchronous Machines and Utilities

General-purpose synchronous assembly machines are available from several sources. An example of a commercially available design that meets the requirements for the electromecahnical section of the PVF is shown in figure II-2 (5). This is a medium-sized machine, 36 in. in diameter (914 mm), having a 24-station indexing worktable above a 4 × 6 ft (1.2 × 1.8 m) cabinet and tool mounting surface. It is a standard system designed for ease of use and flexibility in converting from one job to another. It uses standard tooling modules in an "erector set" or building-block fashion to minimize the time and trouble of setting it up. This would apply to the various jobs expected for the PVF operation. All power for actuating the tooling modules, located either on the lower surface or mounted using predrilled holes in the upper tooling plate, is provided for the central column. Tooling components have overload protection, and their travel can be adjusted to within 0.001 in. (0.0025 mm) in both stroke directions. The main index drive has overload protection on its output side. Station location is provided that is accurate to better than 0.001 in. (0.0025 mm) and is independent of the indexer. These features minimize position error due to wear in the drive system and make it easier to reset the dial in the event of an overload. The main drive system is a 1-hp electric motor with clutch/brake and variable speed pulley. Its speed is mechanically variable from 10 to 50 cycles per minute, thus making it easy both to study problems with tooling and to adapt its use to simple or complex operations.

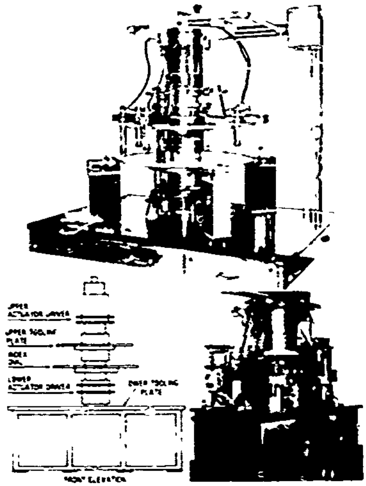

Figure II-2. Views of typical rotary synchronous assembly machine.

A self-contained electrically driven pneumatics package providing vacuum and dry or lubricated pressurized air for tooling is contained in the base of the machine. Sixteen general-use pneumatic valves, timed by means of rotary cam switches coupled to the indexer, are located on the top of the central column and under the lower tooling plate.

Control systems available for synchronizing the operations of automatic machinery range from simple drum-type programmers, through matrix switch and relay systems, to modern solid-state programmable controllers. It is suggested that one of the machines for use in the EM section of the PVF be equipped with a matrix switch type of EM control system (12) and another be equipped with a simple solid-state programmable controller (13) so that experience can be gained with both types of control.

### II-3.4 Tooling

A wide variety of standard tooling modules is available. Some of these are described and their possible uses are discussed below.

a. An automatic spring winder with capacity of 0.002- to 0.030-in.-diameter wire, and with automatic feed, cutoff, and controlled retention or feeding of each spring. This is likely to be a small satellite machine stationed next to the main synchronous assembly machine and feeding directly to a

nest or pick-and-place unit. In order to compensate for minor variations in wire diameter as feedstock is depleted, spring force would be monitored, and dynamic control of pitch or free length would be provided by feedback adjustment

b Orbital and/or radial riveting and cold-forming machines (14, 15, 16) for manufacture and assembly of soft metal parts, weighing up to 0.5 oz. Tooling heads would provide very low force non-impact staking, flaring, and forming They could be used to form small cold-headed parts from feed-stock, or to provide functional features on end-item components and do these operations right on the assembly machine, on demand

c Pick-and-place units for transferring parts and assemblies to and from the transport system, to and from satellite operations (for example, a spin test station), and from feeder tracks into the nests or the rotary worktables These units would encompass translational (1, 2, and 3 axis), translational and rotational (swinging), and inverting motions They would include specific modules designed by the manufacturer of the synchronous machine and general-purpose mechanical and EM units available from specialty firms (17). Important features of the pick-and-place modules would be small size, easily adjustable grips, strokes, and motions, and overload protection to prevent damage in case of a jam or other malfunction

d Small modular press heads (18), for use in assembling press-fitted components as well as crimping and punching operations in thin sections

e Various probe heads, for detecting the presence and/or position of parts or assemblies. There could also be probes for gaging heights (19), sizes, and forces during assembly Special probes could be developed to simultaneously measure force and stroke of spring-biased detent systems during acceptance testing. In addition to simple mechanical displacement monitors that trip limit switches, the probes might incorporate fluidic and photoelectric sensors (20), strain gages (21), linear variable displacement transducers (LVDT s), magnetic sensors (22, 23), and appropriate readout instrumentation

f. Marking equipment, for lot numbering, serializing, identifying, etc , is available commercially (24, 25) and could be set up as a modular operation

g. Resistance welding heads (26), for spot welding of small parts, electric connections, and explosive assemblies They would be small units with adjustable controls for current, voltage, pressure, and duration

h Ultrasonic tooling modules (27), for welding plastic assemblies and inserting metal parts into plastic parts

i Tape blanking tooling, for use in blanking and installing marking and sealing discs from adhesive-backed tape

j Precise volumetric metering heads, to dispense oils, grease, foams, epoxies, and anaerobic and rubber-based adhesives and sealants. A wide range of this equipment is available commercially (28) Equipment to dispense sealants in controlled patterns for formed-in-place gaskets may also be desirable.

k. Automatic screwdrivers (16, 29) having adjustable torque and self-contained screw feed systems for threaded assemblies.

l. General-purpose vibratory sorting and feeding systems (30, 31), these units are needed for many stations In general, these systems need to be 'tuned' each time a new part must be handled, but a broad series of general-purpose units could form a basic operation.

### II-3.5 Automatic Data Processing

A major use of the PVF automation equipment will be in performance-testing EM devices and subassemblies. The large amount of data (both variable and attribute) generated in these tests can be very valuable from the standpoint of process control and general quality assurance if it is processed in a concise and timely fashion. Direct access to computer facilities should be made available for this purpose Within the facility, automatic data

processing could readily be accomplished by direct interface between the sensing probe's readout instruments and SPEAR, HDL's general-purpose computer system planned for installation throughout the laboratories (see also Chapter XII) Another major use of the PVF is to develop automatic EM device test systems that can be shipped to contractor's plants Many of the EM device contractors do not have access to in-plant computer facilities Therefore, use will also be made of programmable calculators for automatic data processing These systems (32), some with plotter and tape cassette drive, can very easily be set up to take and to process data on-line in real time and off-line from storage on small magnetic-tape cassettes. The programmable calculators are small and versatile, a complete system could be set up for approximately $10K or less.

## II-4. Operation

### II-4.1 Method and Capability

The initial use of the EM section of the PVF as an automation machinery laboratory will be to provide in-house experience and competence in this field After this is established, the facility can provide services related to validation of prototype fuze designs For example, it might be set up for assembly and/or test of several hundred to several thousand S&A devices during the R&D phase of a new fuze program However, this use is not recommended now because of conflict with contracting policy Also, the limited amount of equipment is such that a complete job of this nature would probably require several reconfiguring phases Although this might be done in a reasonable time given a highly skilled and experienced staff (see sect. II-4.3) and a well-stocked supply of general-purpose tooling items, it would not be efficient compared to hand assembly In order to minimize changeover time and expense for the small quantity of items that would be assembled, it may be more practical to use hand-loaded magazines instead of vibratory bowl feeders to feed oriented parts The magazines would be loaded off-line. Items of special-purpose tooling requiring considerable time/expense for changeover are the nests for the rotary worktable and/or the pallets for the NS transport system. The designs have to be tailored to the job and they must be replicated many times (see fig II-3) However, it may be possible to devise a general-purpose nest or pallet that could easily be adapted to many jobs

During the initial learning phase and during the development of tooling for the facility, it would be practical to concentrate on automated inspection and testing of developmental S&A devices or on building and testing simple subassemblies such as setback mechanisms or explosive loaded items (see sect II-4.2). A more general-purpose use of the facility would be to study specific aspects of a design relative to its capability for assembly and testing using automatic machinery.

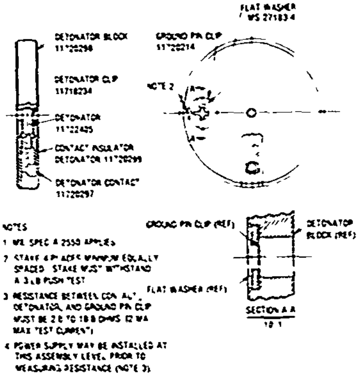


Figure II-3. Detonator block assembly (PN11722620) for XM587E2/M724 fuze.

In addition to its use for prototype validation, the facility would be used to develop new techniques for more efficient automated test and assembly of fuze mechanisms For example, probes could be developed to measure force bias levels at given positions and to generate variable data to replace GO/NO-GO test probes that give only attribute data These probes, plus associated instrumentation and data processing, would be exceptionally valu-

able for process control in production environments As another example, new methods of automatically applying solid and liquid lubricants would be investigated that could lead to more uniform and controllable coatings, giving better performance at lower cost These new techniques could then be disseminated to contractors for improvement of their automatic production lines Studies of the value of data collection, development of data libraries, data analysis, analysis of system operations, feedback control loops, etc, for particular situations would all be conducted

Another use of the facility would be to help contractors in evaluating various methods for automating a new operation or for correcting an operation that is causing difficulty. Different ways of feeding and orienting parts could be explored An opportunity to help a contractor correct a malfunctioning station designed to feed and place small coil springs is a recent example where lack of an in-house facility precluded experimental assistance

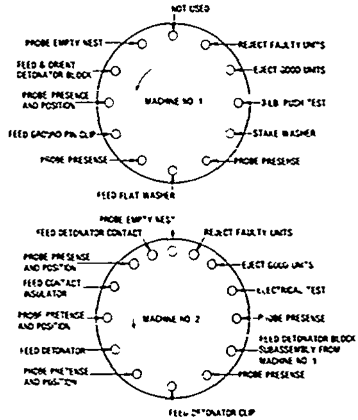


**Figure II-4. Operations for automatic assembly and test of PN 11722620.**

### *II-4.2 Example*

In order to progressively develop in-house automation experience, the PVF EM device laboratory equipment would first be set up to perform simple jobs A typical first job might be to set aside a portion of a production buy of the detonator block assembly for the M587E2/M724 fuze. These units would then be built in house and furnished as Government furnished material (GFM) to the prime fuze contractor A typical quantity would be 5,000 to 20,000 units, representing one device lot The detonator block assembly (PN 11722620) is shown in figure II-3 It is a good test run for the proposed PVF facility because of its small size (1 5 in diam × 0 25 in thick) and relatively simple, seven-part assembly It requires handling and installation of a sensitive electroexplosive component and it must be tested for contact resistance Thus, it provides experience in explosive handling, setup, and use of automated test instrumentation, and computerized data reduction The necessary operations for this job are outlined in figure II-4

This job is laid out on two machines to simplify the tooling and to facilitate the learning process during initial operation of the facility. All probe stations and test stations are separate from the feeding and assembly stations. The operation can be made more compact later by doing most of the probe checks at the same station being used for feeding and placing parts. Photoelectric or other remote-type sensing plus additional control of the feeding and placing operations would probably be required In both cases, a memory system would be used so that feeding occurs only when the probe output is positive. Safety from possible initiation of the electric detonator would be provided by clear plastic shields at all stations after on-line introduction of the detonator. The final assembly would be loaded into magazines that would provide intrinsic explosion containment during storage and shipment

The PVF laboratory EM device could be tooled for two other "beginner" problems of current interest One is the assembly and test of the bottom plate, spacer,and setback lock subassembly for the M732 fuze. This item, shown in figure II-5, is made up of five parts and would require force bias testing of the setback pin and spring The other

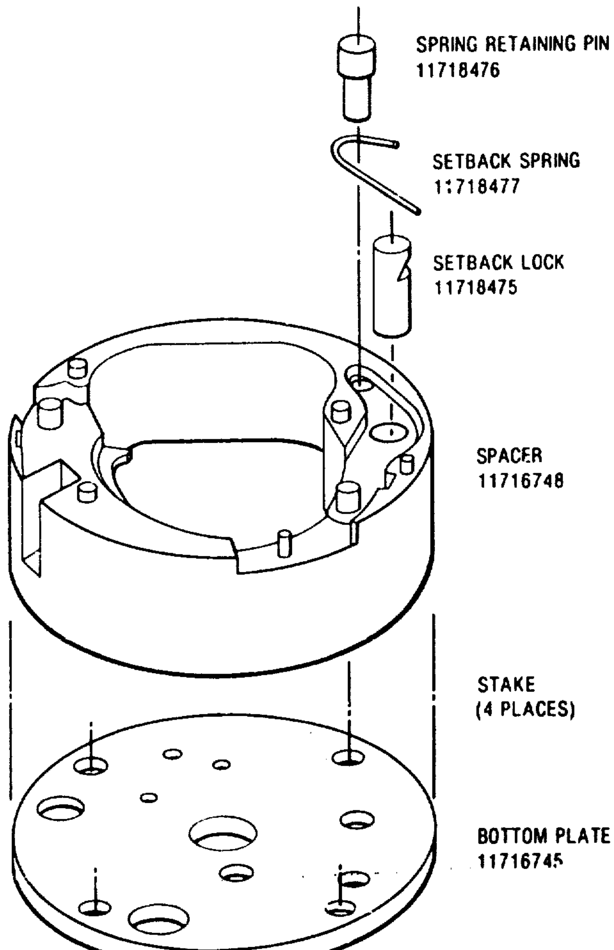


**Figure II-5. Bottom plate, spacer, and spring setback subassembly.**

setup would use the facility for automatic testing of the completed M732 fuze S&A module (PN11716741) shown in figure II-6. This line could serve as an in-house tester for Government inspection of engineering control samples during production. It could also serve as the prototype test model for other units to be set up in contractors' plants. The necessary operations for such a tester are given in figure II-7. The system is again spread out to use the two machines but, in this case, the number of operations might still be too many for later adaptation to a single 24-station machine. This might be compensated for by having faulty units marked with a code instead of being ejected after each test and having certain probe and orientation stations eliminated by means of clever tooling.

Satellite spin machines are used in three places to speed the cycle and provide better access.

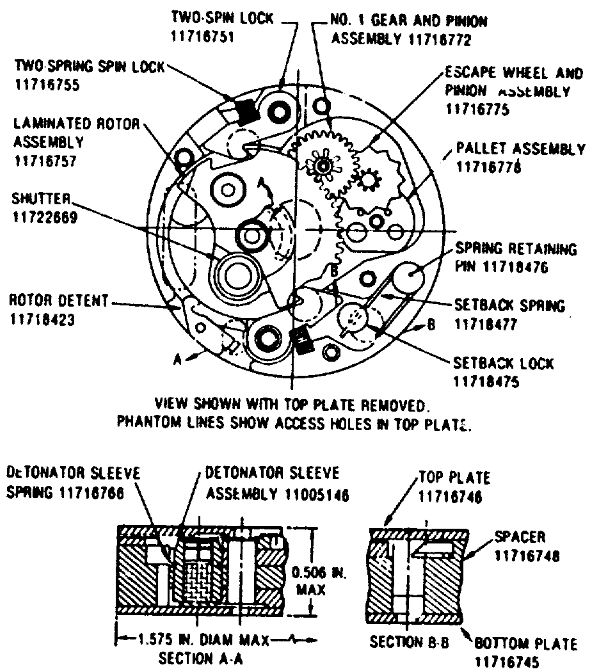


**Figure II-6. S&A module PN 11716741 for XM732 fuze.**

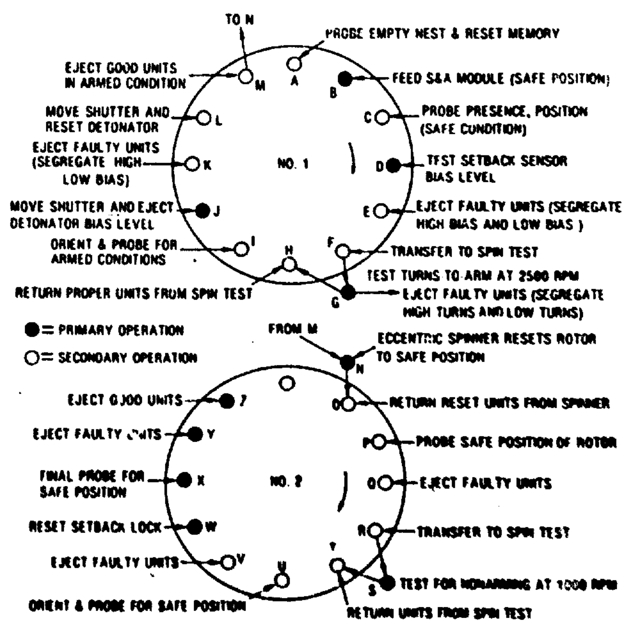


**Figure II-7. Sequence of operation for testing S&A module (PN 11716741).**

## II-5. Conclusions and Recommendations

It is concluded that the proposed I-4 device automation laboratory facility would be a valuable asset in expanding HDL's areas of technical expertise and in supporting the current electronic fuze R&D mission It is recommended that it be included in the planned PVF and that it be staffed and funded full time as a production engineering support function

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John Stackhouse, *The Application of Low Pressure Abrasive Flow Machining* (MR75-840), Dynetics Corporation, Woburn, MA

## Appendix II-A.—Sources of Automation Equipment

The following list of sources of automation equipment was compiled during the study covered by this report There are many other companies in these fields that are not included in the list, but time did not permit searching them out Sources 1, 2, and 3 are general-purpose publications dealing with the field of automation, and they would serve as a good source of additional information in this field

1 *Assembly Engineering*, Hitchcock Publishing Company, Wheaton, IL.

2 *Automation*, Penton Publishing Company, 1111 Chester Avenue, Cleveland, OH

3 *Control Engineering*, Dun-Donnelley Publishing Company, 666 Fifth Avenue, New York, NY

4 Rockford Automation, Inc , Rockford IL (NS pallet transport systems)

5 Assembly Machines, Inc , 2114 Loveland Avenue, Erie, PA (general-purpose synchronous assembly machines)

6 Honeywell, Inc , Dept R1310AU, 2600 Ridgeway Parkway, Minneapolis, MN (synchronous assembly machines)

7 Bodine Corp , 317 Mountain Grove Street, Bridgeport, CT (general-purpose in-line synchronous assembly machines and tooling modules)

8. Gilman Engineering and Manufacturing Company, 305 West Delavan Drive, Janesville, WI (automatic assembly systems).

9 Modular Machines Co , P O. Box 7158, San Diego, CA (general-purpose NS assembly machines)

10 Chicago Pneumatic, 32200 N Avis Drive, Madison Heights, MI, (NS automation systems)

11. Innova, Inc , 5170 126th Avenue, North Clearwater, FL (NS automation systems).

12 Square D Company, Milwaukee, WI (programmable controllers)

13 Texas Instruments, Inc , Attleboro, MA (model 5T1 solid-state programmable controllers).

14. Taumel Noiseless Riveters, Inc , 400 Executive Boulevard, Elmsford, NY (orbital head-forming machines)

15 VSI Automation Assembly, Inc , 165 Park Street, Troy, MI (noiseless orbital forming machines)

16 Gubelin International Corp , 45 Kensico Drive, Mt. Kisco, NY (automatic screwdrivers and radial riveting machines).

17 Fraser Automation, 37900 Mound Road, Sterling Heights, MI (modular pick-and-place units).

18 Conrac Corp , Goodrich Division, 3560 Chicago Drive, Hudsonville, MI (presstaker special assembly machines)

19 Schaevitz Engineering, P O Box 505, Camden, NJ (noncontacting gage heads)

20 Scan-A-Matic, Rt 5 West, Elbridge, NY (photoelectric sensors).

21. Interface, Inc., 7401 East Butherus Drive, Scottsdale, AZ (low-range load cells).

22 Electro Corporation, 1845 57th Street, Sarasota, FL (magnetic pickups).

23 Airpax Electronics Controls Division, 6801 West Sunrise Blvd, Fort Lauderdale, FL (Hall effect pickups)

24. Kiwi Coders Corporation, 4027 N Kedzie Avenue, Chicago, IL (automatic marking equipment)

25 Bristol Brass Corporation, Noble and Westbrook Division, East Hartford, CT (marking stations)

26 Kahle Engineering, 3322 Hudson Avenue, Union City, NJ (automatic welding heads)

27 Branson Sonic Power Company, Eagle Road, Danbury, CT (ultrasonic work heads).

28 Tridak, Inc, 5 Valley Road, Danbury, CT (metering and dispensing heads)

29. Dixon Automatic Tool Inc, 2312 23rd Avenue, Rockford, IL (automatic screwdrivers)

30 Magnetic Analysis Corp, 535 South 4th Avenue, Mount Vernon, NY (automatic checking and sorting machines)

31 Automation Devices Inc, Automation Park, Fairview, PA (vibratory feed systems)

32. Hewlett-Packard, P. O. Box 301, Loveland, CO (programmable calculators and interface instrumentation)

## Chapter III. Semiconductor Prototype Validation Facility

by Robert B. Reams and Martin J Reddan

### III-1. Introduction

#### *III-1.1 Background*

HDL has always had intense involvement in those technologies that could advance the art of military electronics One of these areas has been the field of semiconductors, used by industry to fabricate active solid-state devices (transistors, integrated circuits, etc ) for the commercial market Similar devices are being used extensively in HDL-developed electronic fuzes, radar, and optical systems

The present HDL staff operates a facility which is unique in the Army's Materiel Development and Readiness Command (DARCOM) HDL has conducted semiconductor research, development, and investigation of processing techniques continuously for more than 20 years, commencing with the introduction of germanium transistors, up to the present common use of a multitude of solid-state devices

HDL has made significant contributions to this technology For example, it pioneered in the use of photoengraving in fabricating semiconductor devices This was done before industry converted from the use of germanium to the predominant use of silicon HDL also developed two important techniques that are now commonly used by all semiconductor fabricators a two-step reduction process in mask making and the generation of an array of devices by the use of a step-and-repeat camera

The existing HDL semiconductor research laboratory was set up in part to develop electronic devices unobtainable elsewhere and to provide "hands-on" experience with the problems of producing integrated circuits for military applications. Our present facility is therefore equipped to produce limited quantities of both bipolar and metal-oxide-semiconductor (MOS) devices for advanced prototype proximity fuze designs It has been established through many years of tedious experience that such in-house work is the only practical way to acquire devices that are uniquely relevant to military use It is understandable that private industry has shown little concern in developing the specialized circuits required for military application Their raison d'etre is profit, thus, their primary interests are centered on devices, circuits, and techniques that are related to the mass consumer markets, such as those that apply to fabrication of televisions, calculators, electronic watches, etc Out of necessity, the area of specialized, prototype, low-cost, semiconductor military applications has been relegated to HDL's semiconductor group.

At the present time, the HDL semiconductor research laboratory uses these new technologies as part of a program to reduce the cost of mass-produced electronic proximity fuzes This is one area of investigation in which the HDL semiconductor section has a marked interest, since recent years have brought a sharp increase in demands for lower costs, greater reliability, freedom from maintenance, and use of proven radiation-hardened components

In regard to cost, industry experience shows that the specific economics of diverse integrated circuits makes it difficult to arrive at a meaningful average cost for an integrated circuit, but there is complete agreement that where the production level is sufficiently large, silicon monolithic devices are the least expensive components More importantly, HDL has pioneered and is continuing an effort to provide electronic ordnance functions in an integrated form so that they will be available at lower cost than is now possible with discrete component electronics

As a direct result of past accumulated experience, there resides within the HDL Microelectronics, Materials, and Reliability Branch a detailed

knowledge of the technologies used in fabricating semiconductor devices and circuits for military applications However, the present semiconductor research laboratory has a limited capability The devices that are designed and fabricated there demonstrate operational reliability and feasibility, but not at high production rates The PVF would provide the ability to demonstrate producibility in a more advanced semiconductor facility It will be maintained and operated by research and development personnel, but will include industrial-type equipment so that resulting end items will demonstrate producibility as well as feasibility

### *III-1.2 Problems*

Various, obvious problems have increased emphasis on the RAM concept (reliability, availability, maintainability), which brings to the forefront one of the outstanding, advantageous features of monolithic structures homogeneity This characteristic ensures that tests establishing the reliability of a representative group of devices are meaningful to the entire group when it is known that common and consistent fabrication technology was employed Semiconductor fabrication technology is admirably suited to batch processing, in which large numbers of devices are made in an identical manner

The RAM concept is especially pertinent in the radiation hardening of semiconductor devices because the severity of radiation effects on MOS devices depends on the hardening process used Four HDL facilities are available for evaluating radiation effects These are (1) the cobalt 60 source—an air and water irradiation source, which is used to expose electronic devices and systems to simulated nuclear-ionizing threat environments, (2) the Gamma-Ray Simulation Facility (AURORA), which produces a 100-ns bremmstrahlung radiation pulse with a total gamma dose of 50,000 rads(Si) at the midpoint of a 1-m-diam by 1-m-long cylinder and can evaluate gamma-ray-induced transient radiation effects in electronics (TREE) on large weapon systems, (3) the Transportable Electromagnetic Pulse Simulator (TEMPS), which produces threat-level electromagnetic pulses similar to those produced by exoatmospheric nuclear explosions, and (4) the High Intensity Flash X-Ray Facility (HIFX), which simulates the effects of nuclear-weapon radiation on weapon electronic systems by providing an intense nanosecond burst of photon or electron radiation The proximity, availability, scheduling ease, and minimum paper work required for use of these facilities are all advantages accruing to the HDL PVF More relevant are the many types of radiation and the range of intensities and pulse durations available But most important is the situation that ensures that these tests will be under the direction of the R&D personnel and will be conducted during the earliest stages of circuit development Thus, the PVF will prove to be most effective by making use of available facilities and talent to select technology, components, and circuits at the earliest phases of prototype fuze development

Another factor to be considered is the range of technological capabilities of the PVF, both immediately and in the future It is presently considered that the initial work will be centered on bipolar and complementary MOS materials However, semiconductor technology is expanding so rapidly that the horizons are virtually unlimited, and with the PVF as contemplated, future developments into other technology areas will also be possible.

The PVF would greatly alleviate one problem that now exists making the practical transition between demonstrating feasibility and ensuring producibility It is possible to fabricate an integrated circuit of special function in a limited quantity, but this does not mean that it will then be possible, using similar procedures, to produce these same circuits economically. Thus, the PVF will provide a limited staging area to demonstrate that the circuits are producible with equipment and facilities commonly used by industry.

In particular, four major concerns of semiconductor processing technology have been resolved by industry, but not in the present research laboratory These are

(1) precise control and elimination of airborne contaminants encountered during fabrication,

(2) use of ion implantation to precisely control the distribution of impurities within the semiconductor device,

(3) use of injection-molded plastic encapsulants to ensure ruggedness and survival under military conditions, and

(4) introduction of advanced semiautomatic equipment for use in all relevant semiconductor processes

## III-2. Use of Semiconductor PVF

### *III-2.1 Contaminant Control*

Industrial semiconductor facilities control airborne contaminants by careful design of the total laboratory air-handling system The present HDL research facility has been compelled to limit its air filtration (clean air) control to several specific operations only For example, in the photomask fabrication area, the image-repeater camera must be housed in a special chamber that has a filtered air supply. Unfortunately, the exposed masks must then be carried in covered containers into the processing area, which is not controlled and where the masks can be contaminated. Particles can collect in the container and on the masks, as a result, photomasks occasionally have to be remade because of defects caused by particle contamination In all instances, the operation is inefficient—creating handling problems, causing additional work, and impairing overall mask quality.

Another problem exists with the diffusion processing of wafers At present, these operations must be carried out in an environment where air contaminants can be deposited on wafer surfaces before the wafer is placed in the diffusion furnace. This, too, causes surface defects and results in impaired functioning of the devices.

The contemplated PVF calls for clean rooms where the entire room has a controlled filtered air supply In addition, there will be further refinements in the immediate vicinity of operations in which the process being implemented is especially sensitive to contaminants

### *III-2.2 Ion Implantation*

Almost all semiconductor devices depend upon precise geometrical placement of selected impurities These impurities are now distributed thermally by alloying and diffusion processes using precise photomasks to delineate areas Control to 0 5 μm is typical with these processes, but overall yield is less than it could be since the impurity atoms display wide-ranging dispersion from an ideal distribution. With impurity placement by energetic ion beams, the desired impurity can be placed with greater precision (better than 0 1 μm) and with more precise control of spatial distribution This technique is now being used by industry in processing an increasing number of semiconductor devices to produce better devices with a greatly reduced reject rate The present HDL facility has no ion-implantation equipment, ion implantation is proposed for the new PVF facility

### *III-2.3 Injection-Molded Encapsulation*

In building fuzes, only hermetically sealed devices can be fabricated in the present facility. Although these devices are satisfactory—they are rugged enough to survive most gun-fired environments—they are more expensive to fabricate than injection-molded encapsulations (IME's) Most industrial semiconductor package output is now plastic encapsulated, thus, it can be expected that use of hermetic seals in fuze manufacture will soon be completely outmoded, resulting in higher costs in the future There is a more compelling reason than cost for choosing the injection-molded encapsulations It has been demonstrated that solid encapsulations are required for survival and reliable operation in the more extreme military environments Therefore, HDL will require equipment for injection-molded encapsulation to duplicate industrial-type encapsulation in military electronic systems

### III-2.4 Semiautomatic Semiconductor Processing Equipment

Those who fabricate semiconductor devices in industry are increasing their use of semiautomatic processing equipment, with the following benefits

(1) precise process control,

(2) minimized variations caused by the human factor,

(3) increased production rates, and

(4) reduced costs

Also, money is saved, by the use of less-skilled personnel, who require shorter training periods. In particular, the photoengraving of devices has benefitted from the use of semiautomatic equipment for applying photoresist, for processing plates, and for the stringent cleaning required for device fabrication Modern diffusion furnaces now incorporate elaborate gas distribution systems that provide precise control

Since similar facilities have not been available at HDL, current efforts in the research laboratory have necessarily been limited to hand operations As a result, the end product varies from person to person, and overall yields are generally lower than would occur in an automated system Until now, this process has been adequate to demonstrate feasibility but not producibility Demonstration of the latter will require the use of equipment and methods similar to those used in industry

#### III-2.4.1 Reasons for Equipment Selection

The equipment to be used in the PVF semiconductor facility has been selected as representative of the types used by industry in the production of semiconductor devices (See equipment list in sect III-2.5 ) The equipment listed here has been selected to provide a capability that is not now available at HDL and to bring existing outdated facilities up to the level of current technology. Thus, some items of listed equipment will be quite similar to those now used in the research laboratory, but they will be improved versions, vastly superior to those presently available The goal is to have a versatile, comprehensive semiconductor facility that will

(1) replace the outmoded research laboratory,

(2) permit trained personnel to carry out investigative processing studies, and

(3) use the system to demonstrate feasibility and prove producibility

A PVF at HDL will assure rapid interchange of production-derived information to the research staff, and in this way increase scheduling efficiency, shorten development time, and cut the costs between development to production.

#### III-2.4.2 Detailed Description of PVF Semiconductor Facility

The following describes the work flow and equipment proposed for the PVF Semiconductor Facility

Figure III-1 shows a general layout of the PVF semiconductor facility The work will be initiated in the electronic design area, S-24, where work begins on providing solutions to a project problem using semiconductor technology. Development and production people with complex circuit requirements will bring their needs to a staff of electronic engineers familiar with this technology The engineers will design the required circuits using integrated circuit concepts (for instance, transistors are more efficiently integrated than resistors, as a result, circuits use many active devices and few passive components) This preliminary design will then be breadboarded using components that have been fabricated and shown to be compatible with the planned production process This procedure

permits initial evaluation of the design and allows for some modification and improvement of the circuit before the photomasks are made

The staff of the Semiconductor Facility will then use the interactive phics equipment that is part of the photographic acility, S-27, to generate the required photomasks Three steps are needed to make a photomask

(1) A proven circuit design is converted to a mask layout, representing the specific photomasking steps required to convert a silicon wafer to an operating device This layout is designed to minimize both conductor crossovers and parasitic interaction between subcircuits

(2) The layout is digitized onto a magnetic-tape format that provides the data required by a pattern generator The pattern generator creates an oversized (10×) replica of the desired circuit configuration on a glass photographic emulsion This pattern is then examined for defects before it is in turn used to generate the final size mask

(3) The final step takes the mask created by the pattern generator, reduces it by a factor of 10, and repeats this image into a predetermined array that may be either circular or rectangular, to form the master photomask for that particular level This master may then be used to transfer the image directly to the surface of the silicon wafer or itself be contact printed to fabricate many working masks

This working mask is then part of a series of masks which when replicated on the surface of a silicon wafer, contributes to the completion of a working device Through the use of photographic technology, the original circuit design has been multiplied many times to simultaneously produce hundreds of functional circuits on a single silicon wafer

The following briefly describes the process a raw silicon wafer would undergo on its way to becoming an operational active device

The initial form of the silicon wafer will be approximately 2 in in diameter as purchased from commercial vendors and will conform to HDL's specifications. These specifications will include crystal orientation, resistivity, thickness, fault density, lifetime, flatness, and surface quality.

After incoming inspection, the silicon wafers begin their processing in room S-29 (see fig III-1), where the wafers are chemically cleaned and then rinsed in high purity water. Following this, the wafers are either heavily oxidized in a diffusion furnace to reduce or eliminate surface damage or they are chemically etched in an epitaxial reactor The oxide is then removed, the wafers are chemically cleaned again and reoxidized

Processing now switches to the photolithography room, S-31. The first step is the application of photoresist by spinner techniques Then the first pattern mask is mounted (usually a buried layer or floating collector) The mask is exposed to ultraviolet light, using automatic mask alignment equipment, and then inspected Next, photoresist is removed and the units are carefully cleaned The material is now ready to go to the diffusion furnaces The photoresist pattern has permitted a selective removal of the oxide layer, which thereby defines open regions of the silicon wafer into which selected dopants can be introduced by diffusion to a desired depth At the conclusion of the diffusion step a major part of the fabrication cycle is complete and a new sequence starts The wafer is thoroughly cleaned again, and the wafer is then placed in the production epitaxy facility where a new layer of silicon is grown to specified resistivities and concentrations. The wafer is then immediately reoxidized and brought back to the photolithography room for photoresist recoating The sequence of steps is then repeated as outlined previously. The number of times this sequence is repeated depends upon the device requirements When the last diffusion step has been completed, the oxide removed, and cleaning performed, the wafer is brought to the Planetary Metal Station for metallization with aluminum by evaporation. Typically, for an MOS unipolar technology, 5 to 7 masks are needed, a

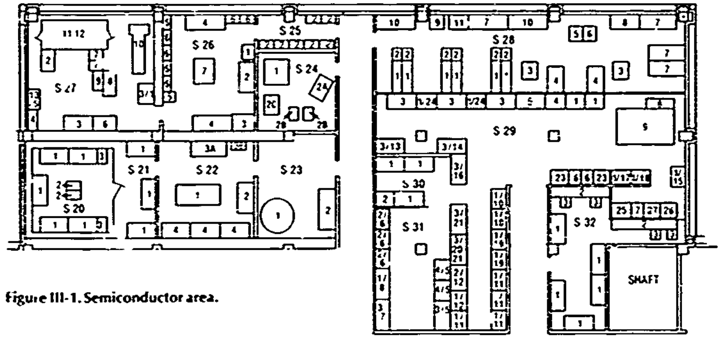



Figure III-1. Semiconductor area.

bipolar technology requires from 7 to 11 masks to fabricate a circuit

In parallel with all the steps described above, test wafers will be set aside for measurement of diffusion depth using the profilometer, the ellipsometer, or the bevel-and-stain technique in combination with the interferometer The scanning electron microscope could be available for checking surface defects

After aluminum metallization, the units are brought back to the photolithography room for delineation of the interconnect pattern Photoresist is again used and the usual steps are followed, after which the wafer is cleaned.

Next, the wafer is sintered in a small furnace.

The wafers are now probed for circuit function, and defective units are marked They are then scribed and broken, and the electrically acceptable chips are visually inspected.

In summary, the following semiconductor operations are common to the processing of most devices to be fabricated in this facility.

(1) chemical cleaning
(2) deionized water rinse of ultra-high purity
(3) thermal oxidation of silicon
(4) chemical etching of $SiO_2$ to delineate diffusion areas
(5) epitaxial growth in a reactor
(6) optical inspection
(7) photoresist application by high acceleration
(8) photomask alignment and exposure
(9) photoresist development
(10) photoresist removal
(11) dopant predepositions (about seven)
(12) dopant drive-ins
(13) diffusion depth measurement
(14) resistivity measurement
(15) surface defect count (optical microscope or, possibly, scanning electron microscope)
(16) interconnect metallization
(17) silicon-aluminum sintering
(18) electrical test by probes
(19) wafer scribing and breaking
(20) visual inspection
(21) die bonding to headers or packages
(22) lead bonding
(23) encapsulation and lid attachment
(24) final electrical test
(25) hermeticity tests
(26) environmental tests

### III-2.5 Minimal Recommended Equipment—Basic Plan

The equipment that would be needed for efficient performance of a PVF semiconductor facility is listed in the following

(a) *Clean-Room Expansion*—Add 25 silicon work stations with exhausts

(b) *Automatic Photoresist Handling*—Add spinners to Photoresist Facility. water spinner device dopants, mask spinner

(c) *Automatic Water Prober*—Add one station

(d) *Automatic Testers*—Add Test Stations for the completed package. linear tester, digital tester.

(e) *Automatic Mask Alignment*—Add alignment and exposure machines projection alignment

(f) *Photomask Improvements*—Add closed-loop focus, add capability for hard-surface pattern generator (on chrome), laser mask inspection and repair tool, automatic emulsion developing system

(g) *Ion Implanter*

(h) *Automatic Die Bonders*—Add two automatic die bonders; add two automatic lead bonders (optical fix)

(i) *Automatic Scribing*—Add automatic wafer-cutting system

(j) *Metal Evaporation System*—Add high-capacity, metal evaporator (planetary type)

(k) *LPCVD*—Low-pressure chemical vapor depositions added to diffusion tubes

(l) *Dry Plasma Etcher*

(m) *Scanning Electron Microscope*—Supplementary but highly desirable (including auger and backscatter x-ray)

(n) *Ellipsometer*

(o) *Profilometer*

(p) *Infrared Optics*- Hot-spot sensing, fault location, failure analysis

(q) *Dry Plasma Stripper*

The equipment described would be installed in the new facility on the second floor of the research and engineering building This would be a complete operating facility containing all the equipment necessary to fabricate complete semiconductor devices, starting with the silicon wafer

Detailed drawings of the equipment layout have been provided (see fig III-1).

The facility as described will be able to provide HDL with the ability to use the following technologies bipolar, MOS, silicon on sapphire (SOS), and integrated injection logic ($I^2L$) Other technologies will also be possible, although they are not included in this plan

### III-2.6 Operational Considerations

The raw materials consumed by this facility are the silicon wafers from which everything is fabricated and the material used during production. Gases probably have the highest use rate. Liquid nitrogen and oxygen are constantly in use; specialty doping gases are also needed for diffusion and oxide growth The facility would also require limited amounts of semiconductor grade acids and solvents, since relatively small quantities are required in each processing step

The mask-making area requires masking blanks which come in a variety of sizes and surfaces

(emulsion, iron oxide, chrome oxide) and the chemicals for processing

The photolithographic area requires various photoresists, their developing chemicals, and stripping solvents.

The only items which would be stocked in the facility would be parts for repairing the processing equipment These would include furnace-heating elements, diffusion tubes, quartz tubes for epitaxial reactors, and electronic component boards for the control devices

## Chapter IV.—Prototype Validation Facility for Fuze Power Sources

by Frederick G Turrill

### IV-1. Background

Electronic fuzes require a source of power and, in almost all cases, it is provided either by an electrochemical or a wind-driven, electromagnetic power supply Shelf life limitations and safety requirements generally rule out the use of active batteries, hence, rockets, mortars, bombs, artillery, and mines generally employ reserve-type (liquid or thermal) batteries, turboalternators, or fluidic generators The associated technology base is highly specialized and radically different from that of the commercial battery or generator Most of the research and development that extends the state of the art in this technology area is carried out in government installations To maintain continuity, minimize munition costs, and assure reliability of ordnance electronics, it is necessary to maintain this expertise in the Army's Development and Readiness Command

Although these PVF activities will support generic power supply systems, specific power supplies associated with four fuze systems have been selected for discussion These four fuzes will probably be produced soon, they are the FMU98, M587/M724, XM734, and M732 (in production) The corresponding power supplies are the PS115, PS113, PS127, and PS602 These units are thus taken as the models for the design and format of operations deemed applicable to power supplies in the foreseeable 5- to 10-year time frame The PS115 and the PS127 fall into the category of aqueous reserve batteries, the PS113 fits the category of thermal batteries, and the PS602 is a wind-driven turboalternator The facility will also accommodate wind driven fluidic generators such as those expected to find service in the second-generation class of 2 75-in rocket fuzes This design approach permits the power supply technology area to fulfill immediate program goals, yet be sufficiently flexible to adapt readily to advancing technology

The PVF will make it feasible for power supplies to be fabricated that use techniques and processes that are very close to—or can readily be adapted to—those used by commercial manufacturers. Although a complete production capability will not be available within the PVF, the tooling and processes to be used will demonstrate and prove the techniques required for large-quantity commercial manufacturing In addition, materials will be evaluated as to their suitability for satisfying performance criteria and their adaptability in fabricating the required power supply A power supply design will often contain parts that are unique in design, inherently expensive, and occasionally no longer available in the commercial market The HDL PVF would provide a capability for ready evaluation of substitute materials and items with respect to functional design, performance, and cost

The PVF would include final acceptance testing to evaluate the quality of the completed power supplies Normally, the aqueous and thermal power supply tests are destructive, whereas the air-driven power supply tests are nondestructive Test equipment would be automated as much as possible, but most final power supply data acquisition would be limited to accept/reject criteria, as would be required in commercial production

The PVF for the HDL Power Supply Branch would be in two areas the existing Branch area and the proposed PVF annex The Branch facilities would include the laboratory, a test area, and a dry room The laboratory area would be used when personnel were working with acids (electrolytes), as when filling and closing copper ampules for the power supplies The test area would house test equipment, the high-speed spinner, bench-mounted air guns and spinner, as well as wind-tunnel, data-acquisition, and data-processing equipment To accommodate power supply environmental tests, coaxial cables would be connected to the test area to record data The space for the

laboratory and the test area is 864 ft² The dry room would include an additional area of 1690 ft², with the relative humidity maintained at less than 3 percent The dry room is necessary for thermal power supply work since the electrochemical components are moisture sensitive. This area also requires a machine capability that will include a lathe a mill, and various hydraulic and mechanical kick presses The aqueous power supply systems can tolerate relative humidity up to 40 percent Therefore, such equipment could be located in the PVF area where this relative humidity could easily be maintained The rotational and fluidic generator activity would also be located in the annex

To demonstrate that the PVF can produce power supplies with high reliability and high quality, a substantial number of units must be fabricated A guideline for this number would be fabrication of 500 to 5000 units at a maximum rate of 1000 per month A quantity of less than 500 is not enough to demonstrate potential assembly processes The number 1000 represents completed power supplies, whereas individual piece parts could be assembled at a higher rate, consistent with commercial practices

The power supply systems presentation for the PVF will first cover the aqueous system and will then be followed by a discussion of the thermal and air-driven systems The PS115 system (aqueous) is in production It has progressed through conceptual design and initial in-house development, about 1,000,000 units have been manufactured by commercial sources In the following presentation, particular portions have been extracted from the conceptual study to illustrate the PVF approach The illustrated concepts are also applicable to the PS127 power supply and other aqueous systems The main difference between the PS115 and PS127 is the method in which the copper electrolyte ampule is hermetically sealed

To support this PVF effort, general machine-shop and special-process equipment is needed It is assumed that such equipment would also support other facility activities Examples of equipment and services required to meet the power supply effort follow

- Press, either a "C" frame or straight side with a capacity of 30 tons and a stroke rate of 150 per minute, of bed size 24 by 16 in and able to accommodate a 600-lb progressive die Automatic feeds and stock reels would be required

- Injection molding, semi-automatic, capacity of a four-cavity mold, each cavity requiring 2 oz

- Sintering furnace

- Die casting, 3-oz capacity for either aluminum or zinc

- Plating and tool/die facility

- Stamping, staking, and roll-forming machines.

- Lathes, mills, etc of a variety to demonstrate production quantities

Proposed additional equipment required for each power supply system is included separately in its section, except for the test and evaluation equipment This test equipment is a basic requirement for any power supply system built in the PVF Equipment cited for each power supply system would be supplemented additionally by existing Power Supply Branch equipment, detailed as follows

### *Equipment on Hand*

Dry room, 1690 ft²
Pyrotechnic room, 338 ft²
Acoustic room
Pellet press
Spot welder
TIG welder
Ultrasonic welder
Solder, induction
Kick press (2), 5-ton
Hydraulic press, 5-ton
Hydraulic press, hand (7)
Shear/punch, hand
Ovens (+160 F) (7)
Hydrogen annealing furnace

Annealing furnace (2)
Vacuum oven (3)
Abrasive cleaner
Ball mill (3)
Test and evaluation equipment
  Electronics
  Spinner
  Environmental
Support machine in dry room
  Lathe
  Mill
  Drill press

## IV-2. Aqueous Power Supplies

### *IV-2.1 PS115*

The PS115 power supply (fig IV-1) is a lead lead dioxide reserve energizer using a copper ampule as an electrolyte reservoir The power supply s initiation and functions are described below

The power supply as assembled is an inert, sealed unit encased in a plastic housing with protruding wire leads for connection to the fuze The chemical reactants are kept separate by enclosing the electrolyte in a sealed copper ampule

Upon encountering the setback and spin forces generated on a projectile during firing, a weight enclosed in the ampule collapses the cutter blades, piercing the diaphragm This allows the electrolyte to flow into the cell stack via the fill hole The methylene bromide, a heavy, nonconductive liquid, sequentially flows from the cartridge behind the electrolyte and masks the cut edges of the fill hole, preventing intercell short circuits In this active state, an electrochemical reaction occurs within the cells between the alternating lead and lead dioxide surfaces, which are insulated from each other by fishpaper separators The 19-cell series stack develops an open circuit terminal voltage of approximately 30 Vdc

A production manufacturing process is illustrated in figure IV-2 The feasibility of the production and process concepts outlined on the drawing are the result of an engineering study

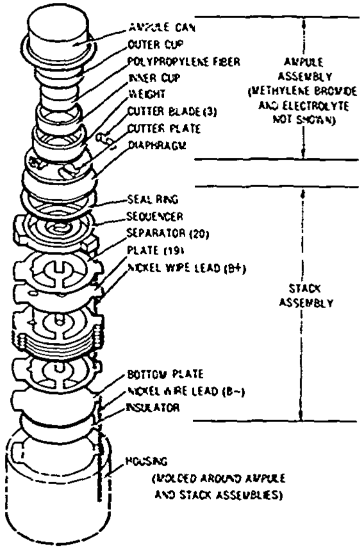



**Figure IV-1. Aqueous power supp... assembly.**

These concepts are a valid starting point for specific equipment, tooling design, and fabrication methods The drawings also depict the ultimate production-line handling methods which in some areas will be simplified for the PVF These differences will be explained station by station in the text and in appendix IV-A

During the setup of any production line, problems usually arise with tooling and methods and persist until the bugs' are worked out Although the manufacturing methods are unique, HDL has had some similar experience and can anticipate specific problems regarding the PS115 line These areas are ampule sealing, cutter and blade assembly, electrode and ampule assembly bonding, and injection molding of the final assembly

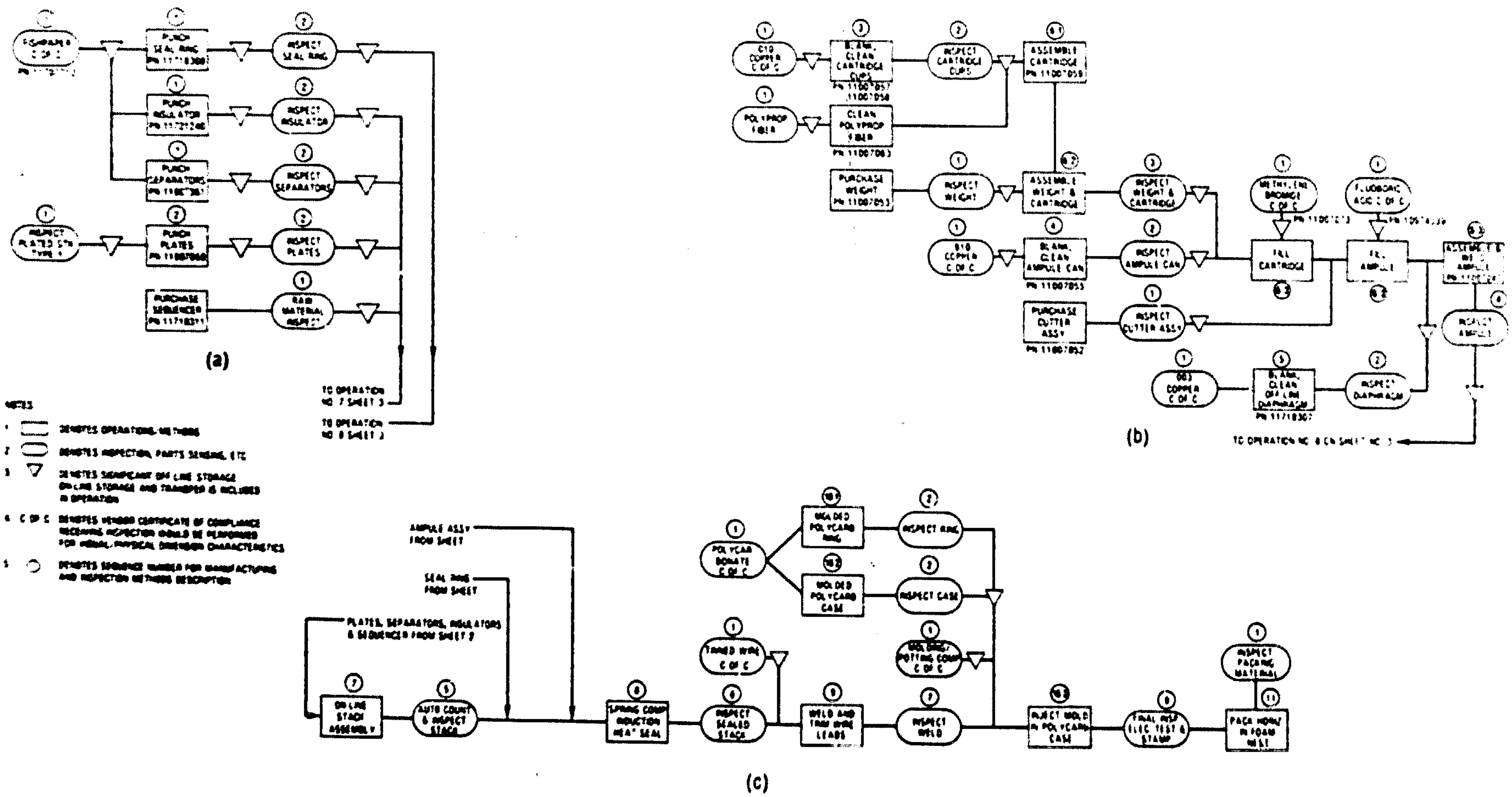



Figure IV-2. Aqueous power supply production manufacturing process.

The main problem associated with the sealing of the ampule can is containing the electrolyte in the ampule during welding, which is very difficult since the ampule must be filled with the acid almost to it's lip. Maximum acid is used because the physical volume of the ampule has to be kept to a minimum and also because excess air is undesirable where fluoboric acid and copper are present. Therefore, any movement of the ampule may spill acid onto the weld area and spoil the seal. Also, if the welding process (generating heat) is not quick and efficient, the liquid may expand onto the weld area or vapors may be generated that will cause blow-holes.

The assembly of the blades to the cutter plate is a problem because the small size and intricate shape of the blades cause them to tangle and bunch up when handled in bulk. Also, the alignment of blade to cutter is exceptionally critical. Another factor that has not been resolved is whether to set the 90-deg bend in the cutter plate before or after assembly with the blade, or to assemble at 45 deg.

Problems encountered in electrode and ampule assembly bonding will greatly depend on the development and selection of the fabrication methods. The complete electrode assembly sequence and ampule assembly must be subjected to a heat cycle in order to achieve adhesion of the polyethylene coated (bonding agent) fishpaper separators and spacers. Induction heaters are planned to be the heat source—a method that has not been attempted previously on this type of power supply.

The final molding of the plastic housing around the electrode and ampule assembly will also present many problems. Mold design will be critical since the electrode and ampule assembly must be held in place firmly but without any deformation. Molding control parameters such as heat, pressure, cycle time, cure time, etc. will have to be controlled precisely to prevent overheating the ampule and causing plate misalignment.

In all the above areas, a prime advantage of the PVF is the availability of equipment for one to investigate and resolve problems before entering into any large-scale production. This will ensure the smooth transition from in-house development to production at a contractor's plant with the Government personnel having more than adequate knowledge to intelligently guide the contractor.

The following described process will include inspection stations at appropriate points. These stations will ensure that the raw materials, individual piece parts, or assemblies comply with the drawing specifications.

Although the PVF is not a manufacturing plant, its purpose is to prove or establish techniques for component manufacture. It is thus apparent that many procedures of the PVF will be entirely suitable for a manufacturer's facility.

*Ampule Assembly.*—Figure IV-3 shows the relative position of the 10 parts of the ampule assembly. The flow process is outlined on figure IV-2. A straight-line intermittent system, shown in figure IV-4, was selected for ampule assembly. This scheme has the advantage of imparting flexibility to work station placement and ready addition of future stations. Additionally, work stations may be positioned to afford greater maintenance accessibility. Also evaluated was an ampule assembly on an automatic assembly machine using an eight-station intermittent dial as its nucleus. The disadvantages of an intermittent dial were that it would be too crowded for efficient maintenance and would not

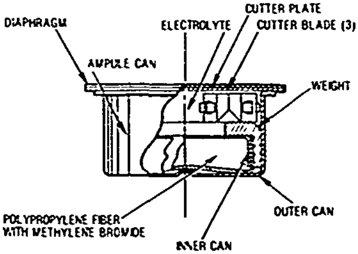



Figure IV-3. Ampule assembly.

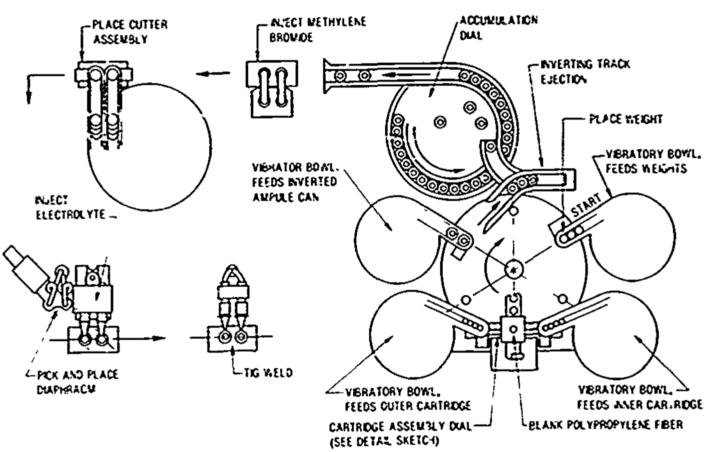



**Figure IV-4. Mechanized ampule assembly.**

be easily adaptable to the addition of future work stations. Because of these disadvantages, the circular dial-plate method was dropped.

The welding station will be the pacing operation on the proposed production ampule assembly system. A 6-s cycle is estimated. Details for ampule and cartridge assembly are described in appendix A.

*Cutter Assembly.*—The fabrication of the cutter assembly components, its cutter plate, and three cutter blades, would present no problem. The configuration of both parts is easily achieved from standard die design practice.

The assembly methods pertinent to the above parts are, however, extremely limited. A die-set assembly scheme is not considered to be feasible because of the proximity of the parts, their right-angle assembly, and the hinges and tabs inherent in the cutter plate design.

The nucleus of the cutter assembly machine is a punch press equipped with a pneumatic intermittent motion (four-station, dial-type), shown in figures IV-5 through IV-7. This type of equipment is available as a standard item, although modifications may be required. The modifications anticipated may necessitate additional press clearance and relocation of tooling mounting surfaces.

The cutter blades are to be formed and blanked on a 1-on die, using the 30-ton Minster press at a rate of 300 blades per minute. Blades will then be cleaned and heat treated. The cutter plate will be conventionally die cut, although not blanked, on the assembly dial press. A departure from convention will be that the hinges (which eventually support the cutter blade) will be formed in the die to 90 deg and then ironed to their original flat position. This operation will allow flat placement of the blades, yet impart a "bend memory" to the cutter plate hinges for reforming after installation of the cutter blades.

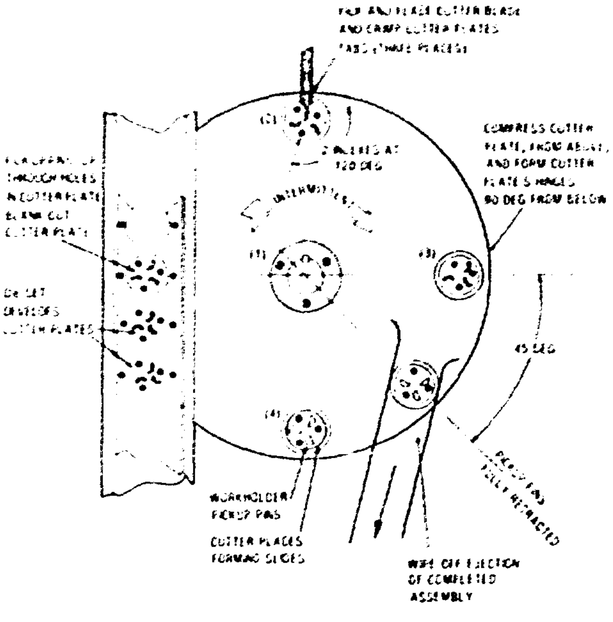


Figure IV-5. Cutter assembly.

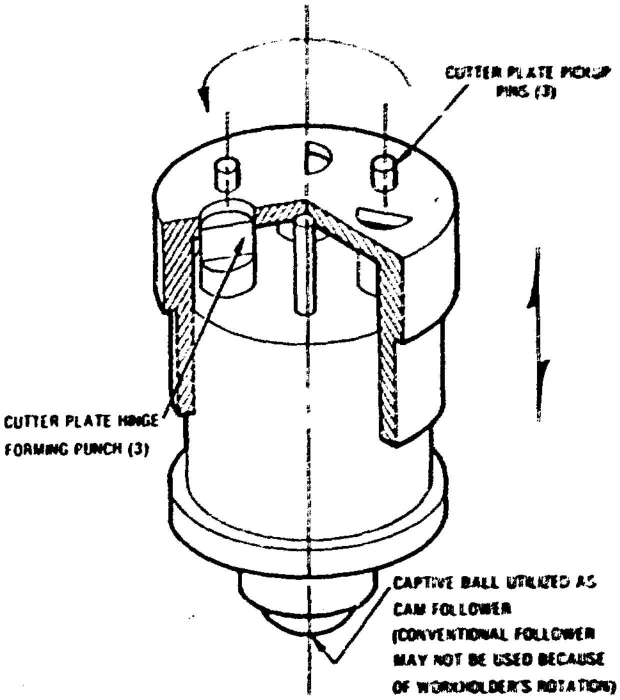



Figure IV-6. Cutter assembly—workholder.

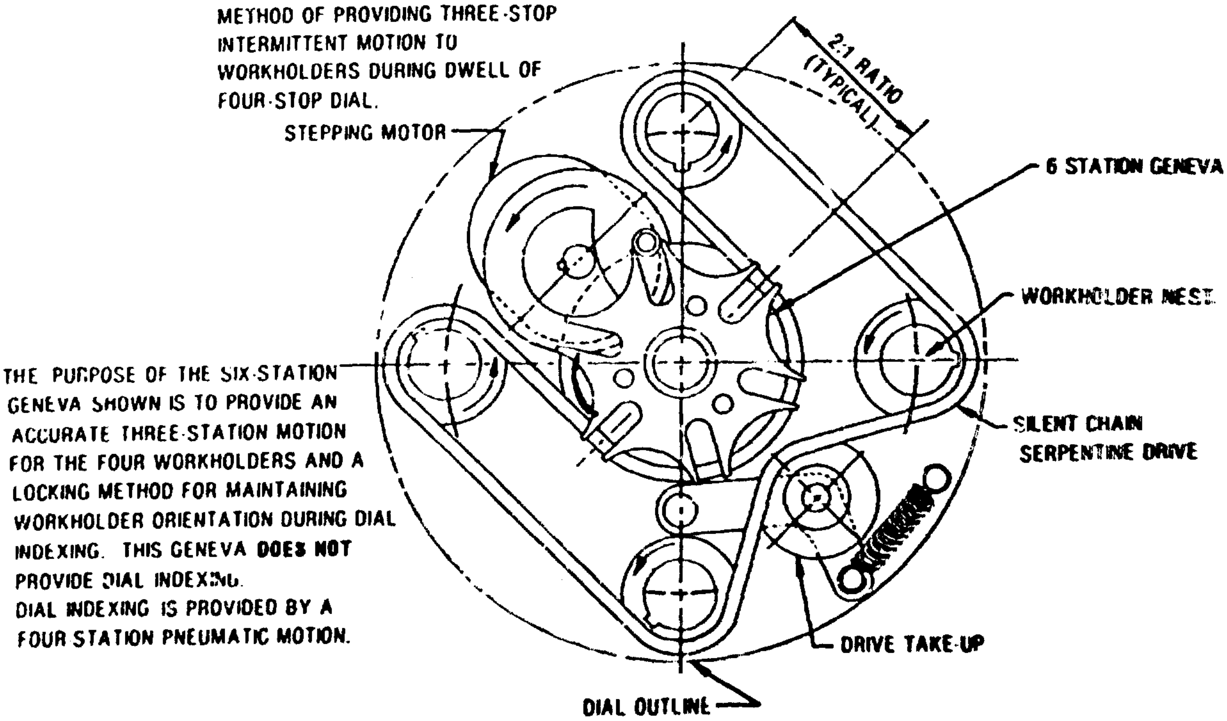



Figure IV-7. Cutter assembly workholder mechanics.

Another suggested procedure will die form the cutter plate hinges to 45 deg before assembly and bend them to the vertical after cutter blade installation Details for this proposed method are in appendix IV-A at the end of this chapter

*Stack Assembly* —The PS115 stack assembly consists of an ampule assembly, a seal ring, a sequencer, 20 separators, 19 plates, an insulator, and 2 wire leads, shown in figure IV-1

The process flow is outlined on figure IV-2

The seal ring, separators, plates, and insulator are blanked from coil stock on progressive dies, two parts per press stroke, through the die set and into a holding magazine, shown in figure 'V-8, at a production rate of 200 parts per minute (press speed 100 strokes per minute), using a 4-ton hydraulic press

The process of building the electrode and ampule assembly will occur within a closed-line system, figure IV-9, at a rate of 18 units per minute for the PVF The PVF will deviate from the planned production-line conveyor system and instead use a tote tray to transport the workholder (fig IV-10) from station to station The workholder contains a die spring in the center which, when compressed 0 25 in to the stops, creates a 250-lb force on the stacked unit The guides used in stacking are made out of a nonconductive material, such as glass-filled nylon, which will withstand 300 F heat The clamping dogs are steel and ride on a sliding track The four holes on the outer corners are used for alignment on the compression and heating indexing unit Points of contact with fishpaper will be Teflon coated to prevent sticking of the polyethylene. The details for the assembly are described in appendix IV-A

*Compression and Heat Seal* —The production facility will have three sets of induction heaters, the PVF will use one set (fig IV-11) Appendix IV-A describes the series of operations which occurs at this station

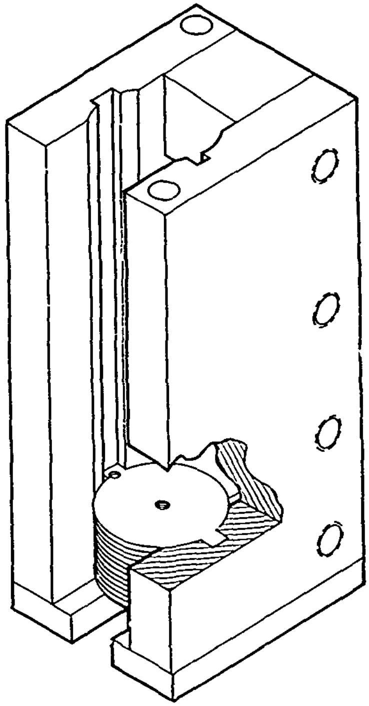
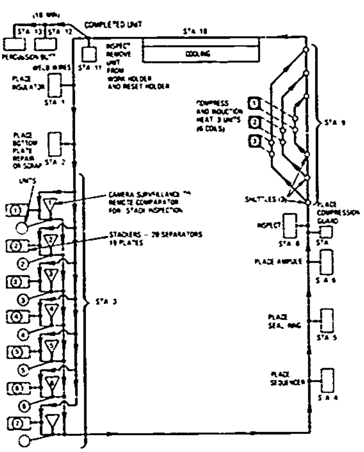


**Figure IV-8. Magazine for separators and plates.**

*Wire Welding* —At stations 12 and 13, figure IV-11, semiautomatic systems will be used for percussion butt welding The welder's two wire leads will be designed with a weld monitoring system Units will be manually loaded at station 11 The wire will be automatically fed, straightened, cut, and welded at stations 12 and 13 The wire will be pretinned nickel or, if the pretinned wire causes problems in the welding area, nickel wire will be used, requiring a wave tinning operation



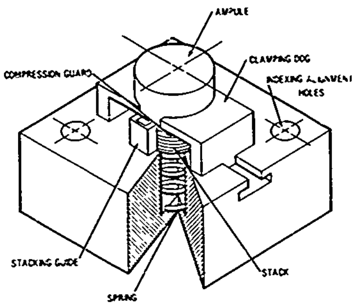




Figure IV-10. Stacking workholder.

Figure IV-9. Electrode and ampule assembly line.

NOTE
(1) STACKING GUIDES ARE UP DURING ENTIRE OPERATION
(2) WATER COOL RAM OPTIONAL IF NECESSARY TO HAVE PROPER COOLING OF AMPULE DURING HEATING
(3) INDUCTION COILS WILL INDEX DOWN, ENCLOSING THE LOWEST PART OF THE UNIT AS INDICATED IN NO 3

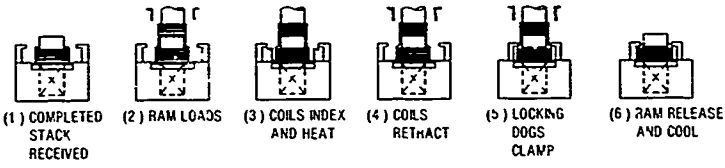



Figure IV-11. Compression and heat seal.

*Final Assembly (Injection Molding)* — From wire welding, the electrode and ampule assembly will proceed to final assembly. Insert molding is the proposed method for final assembly of the electrode and ampule assembly into the unitized power supply configuration. The ampule assembly will be centered in a mold cavity and protected by a premolded locator and ampule protector, which will also provide lateral support for the cell stack. A premolded bottom support plate will locate the stack and provide a means of applying pressure to the cell stack during insert molding to ensure that the seal between the plates and insulators remains intact (fig. IV-12). These two parts will be assembled with the electrode and ampule assembly and loaded as a unit into the bottom half of a mold, positioned on an index table. A complete mold for this operation consists of two bottom cavities and one top cavity. With the bottom cavity mounted on an index table it is possible for an operator to remove the molded power supplies and load the inserts while the second cavity of the mold is in the molding cycle.

Injection molding of the power supply will provide a completely sealed assembly. The wires will be positioned more precisely than could be expected if the housing were first molded and then the assembly was held together with epoxy.

One vertical clamping molding machine with a four-cavity mold (one top half and two bottom halves) will be required.

*Final Inspection* —Finished units will be inspected visually for obvious defects, e.g., wire tinning, voids, flash, leakage, or other physical damage. Dimensions will be checked for conformance to drawing requirements.

Nondestructive electrical tests for cold voltage (150 mV maximum), insulation resistance (200 Mohm minimum when measured at 200 Vdc), and possible capacitance will be performed on a single slide-loaded nondestructive tester with a fault indicator for each test.

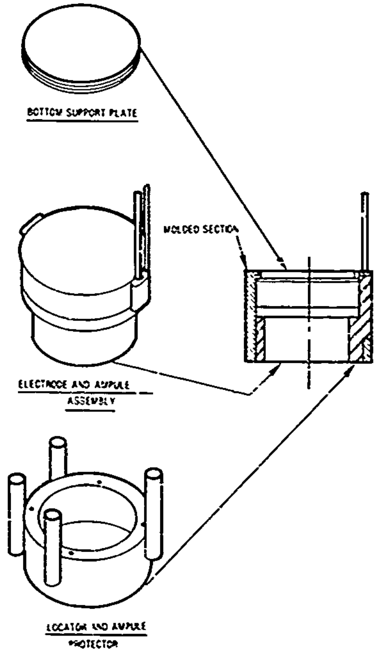



**Figure IV-12. Final assembly by insert molding.**

*Operational Spin Tests* — Sample units will be selected from each lot, the quantity will depend on lot size. Tests will be conducted at spin speeds of 45 to 360 rps on units conditioned at -40 to +140 F.

The electrical characteristics, voltage, and noise of the tested power supplies will be monitored on a test console for compliance with the optional requirements. The console will record all data and visually indicate the failure mode if an out-of-specification condition occurs.

Engineering evaluation tests will also be conducted to establish the ability of the power supplies to meet operational requirements after being subjected to any combination of the following environmental conditions: (1) transportation vibration, (2) thermal shock, (3) storage, (4) drop tests, and (5) jolt/jumble.

Following spin testing, rapid case removal is an important prerequisite to valid postmortem inspection of reserve power supplies. However, the PS115 power supply design does not lend itself to the simple rapid decasement practices incorporated on conventional reserve power supplies.

The method suggested to facilitate rapid and economical case removal requires special apparatus depicted by figure IV-13. The operation of this concept follows.

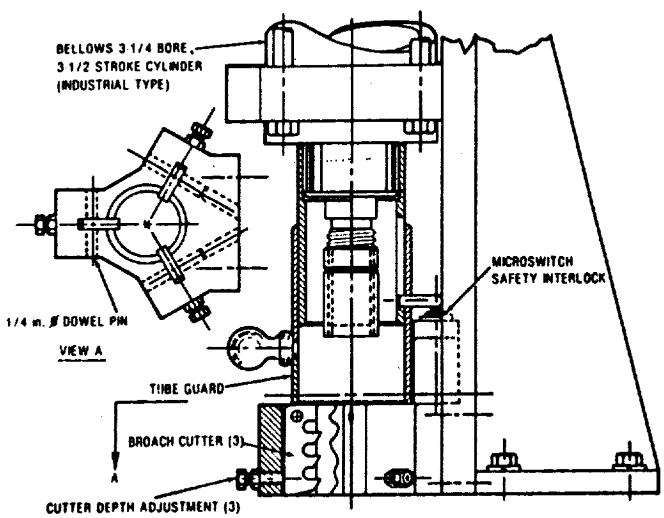



**Figure IV-13. Postmortem broach detail.**

The tube guard is raised, telescope fashion, and a power supply is placed in position. With the tube guard lowered, the air cylinder is activated by a momentary contact switch. The ram pushes the power supply past the broach cutters and the unit is ejected, its case broached to the stack in three places by the keyway cutters. It is now ready for further manual decasing with pliers.

### *IV-2.2 PS127 Ampule Sealing*

Ampule sealing for the PS127 power supply uses the technique of tungsten inert gas (TIG) welding. While thousands of copper ampules have been successfully TIG welded singly, the process has not been automated. Automation, which would not be difficult, is described as follows.

The copper lid and ampule case would be positioned by syntron vibratory bowl feeders onto a rotary table and held in position by vacuum. The cutter assembly would be inserted into the ampule case, electrolyte would automatically be dispensed into the ampule, the lid would be placed on top of the ampule case, and a die with a mating projection to the die on the welding electrode would be positioned to the ampule. The ampule assembly will rotate in approximately 7 s to complete the weld. The completed ampule would then be ejected from the table. The completed ampule assembly would then be heated in a 160-F chamber and observed visually for leakage to determine weld integrity.

### *IV-2.3 Electrode Material*

To supply the variety and quantity of electrodes required for the aqueous power supplies, a continuous strip plater would be located within the PVF. The PS115 power supply is constructed with a duplex electrode: positive material (lead dioxide) on one side of a thin steel plate and negative material (lead) on the other side. The PS127 power supply is of parallel construction: the electrodes are of two varieties. The positive electrode has lead dioxide on both sides of its steel plate; the negative electrode has lead on both sides of its steel plate. The plater required to produce such material would require electrical, water, and environmental services. The physical size of the plater would be 45 ft long by 18 ft wide, an area of 570 $ft^2$. Ceiling height would be 16 ft unless such a height was not available; a lower height of 8 ft would result in increasing the length to 75 ft for a total area of 1350 $ft^2$. The plater would consist of tanks arranged in series, with rollers and guides arranged on top of the tanks. Possible tank overflow would require that the floor be chemically resistant. Arranged along the tanks

would be water pipes and electrical conduits The electrical supply would consist of seven rectifiers, the maximum requiring 300 A at 20 V Deionized water equipment and holding and mixing tanks would be located alongside the plater Spent solutions would require treatment before disposal to meet environmental requirements The electrode material required for manufacture of the anticipated power supply quantities would range between 100 to 1000 ft² for each variety The time required to produce this quantity would be a maximum of seven days for 1000 ft² quantity After plating the electrode material would be slit into widths suitable for the dies used to punch the electrode configuration

## IV-3. Thermal Power Supplies

### *IV-3.1 Background at HDL*

Thermal power supplies have been used in military hardware for about 25 years A significant technological advance occurred when the electrolyte and heat elements were formed as pellets resulting in an overall simplification of the manufacturing process In the more recent thermal power supplies, electrolyte pellets and heat pellets are used in the cell stack in place of the coated metal strip and heat pads used in the PS113 power supply The cell stack is thus an ordered arrangement of disk-type parts the bimetal anode, the electrolyte-depolarizer pellet, and the heat pellet

At this time, HDL intends to concentrate on the use of the homogeneous depolarizer-electrolyte binder (DEB) pellet and the two-component heat pellet To date, only one all-pellet thermal power supply has been developed at HDL, this is the PS413 (PN11764881, which operates for 60 s in the range from 24 to 30 V under a 24-ohm resistive load Since it is an existing unit with a Technical Data Package (TDP), it will be discussed here as a working model for a prototype manufacturing line

In connection with thermal power supply manufacture, a number of things must be considered

First, some of the active materials used in the power supply are highly moisture absorbent, and some of these are irreversibly degraded by moisture pickup If moisture were to be absorbed by these materials before final completion of the power supply, the power supply would be useless. This, then, defines the need for dryness of all materials used within a thermal power supply and the need for a dry-room working area for thermal power supply assembly In thermal power supply manufacture, therefore, a strict procedure must be followed to achieve maximum dryness of all materials used within a power supply before it is hermetically sealed in a metal can

Second, a number of special materials are used in a thermal power supply which present potential health hazards and whose preparations require complex equipment and skilled personnel. These materials are part of the active chemical systems that make the power supply work. The anode material is a thin film of vapor-deposited calcium on a thin metal substrate. The electrolyte or DEB material in this case is a four-component mix formed by a series of mechanical and fusion operations of the two types of heat materials used. The chief heat material is a blended pelletized two-component powder. The other material is a pyrotechnic powder intermixed with inorganic fibers to form a paper-like material. This "paper" is cut into narrow strips for use as fuze trains

The remaining materials—such as the thermal and electrical insulations, the container, consisting of a drawn steel can and lid or header, with insulated terminals, an ignition device, a primer or match; and leads to connect the stack to the terminals—are usually purchased in bulk or lot quantities

The flow chart of figure IV-14 shows the flow of materials and piece parts for the fabrication of the PS413.

### *IV-3.2 Preparation of Chemically Active Materials*

The preparation of various chemically active materials will now be described.

*Anode Stock.*—The anode stock is the calcium-coated steel or nickel bimetal strip stack from which the anode piece parts are punched. The calcium is vapor deposited upon the steel or nickel strip material, which is wound on a drum. During coating, the drum is in a vacuum chamber with an induction-heated crucible, containing calcium metal, running along the bottom of the chamber paralleling the drum. As the drum is rotated, the calcium evaporates from the crucibles and condenses on the steel strip. The thickness of the calcium coating on the steel is determined by the total exposure time and the rate at which the calcium evaporates. The length of the winding depends on the width of the strip stock being used. This is a batch process, requiring specialized equipment, skilled personnel, and dry-room work space. The complete process is outlined by the block diagram in figure IV-15. As visualized at this time, the bimetal facility would be installed in the dry room of the Power Supply Branch.

*Depolarizer-Electrolyte Binder (DEB Powder).*—This binder is the most complex of the chemically active materials in the thermal battery. Preparing the DEB powder includes weighing out the materials; fusing the materials; granulation, sieving, or classification of the fused materials; and pressing the final powder into pellets. Since the material is very dusty, controlling this dust requires good housekeeping techniques. The block diagram, figure IV-16, shows the manufacture of the DEB pellet.

*Iron Powder-Potassium Perchlorate Heat Powder*—This material is a blend of special iron powder, such as Pfizer NX1000 and Exide "Edison" iron with finely ground potassium perchlorate.

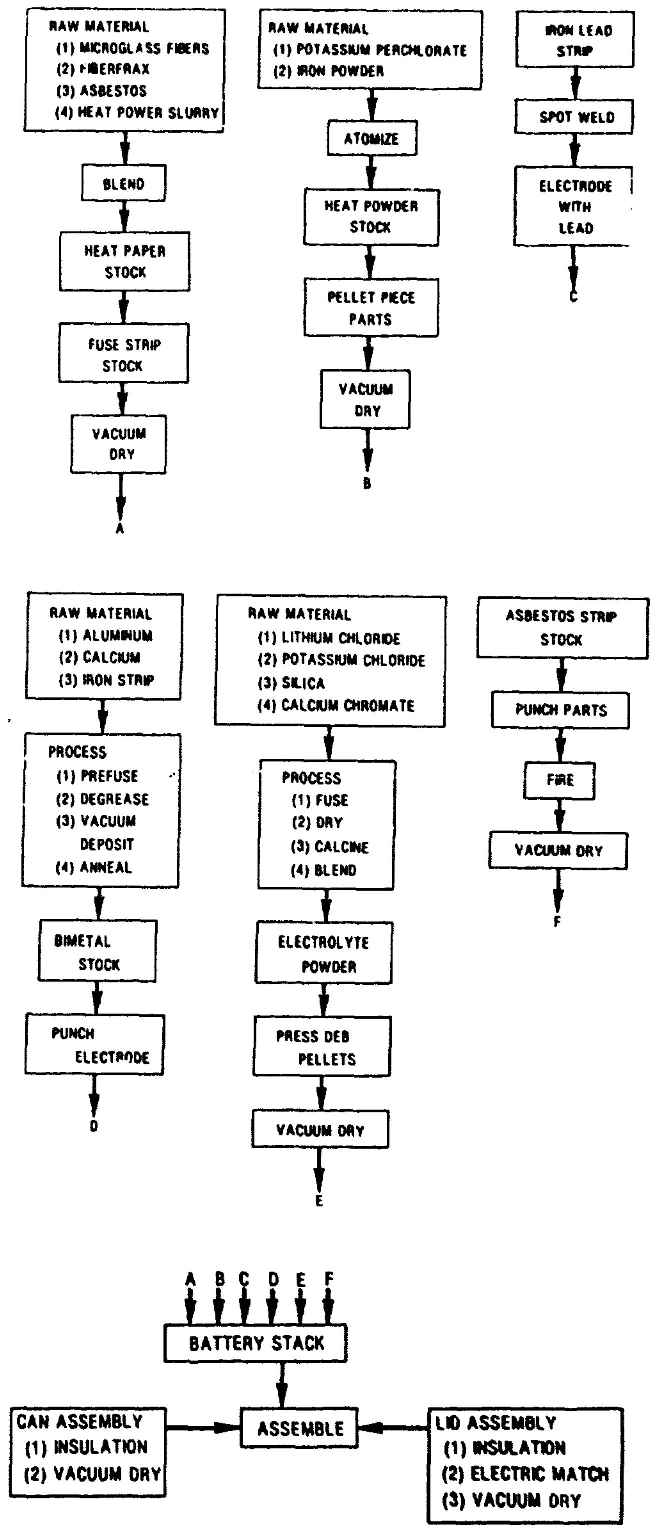



**Figure IV-14. Thermal battery assembly.**

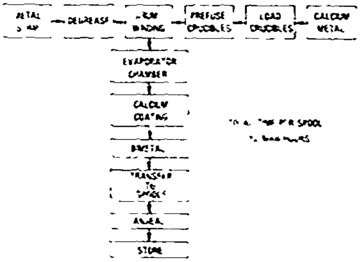


Figure IV-15. Anode stock.

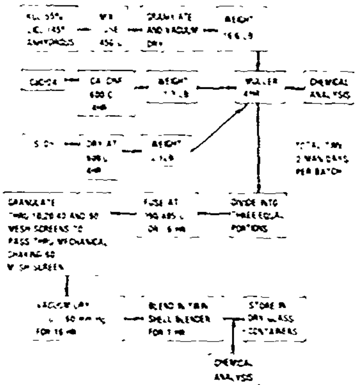


Figure IV-16. Depolarizer electrolyte binder.

Its manufacture involves blending or mixing. In the PS413, this heat powder consists of 86-percent iron powder and 14 percent potassium perchlorate.

The weighed amounts of atomized perchlorate and iron powder are blended, and a smear test is used as the visual test for uniformity of mix. The blended material is stored until ready for use. Several tests, however, are made to check the material, pellets are made to measure ignition sensitivity and burning rate, and a calorimetric test of a given weight of the mix is also made to verify its heat content.

*Heat Paper to Fuse Train*—Heat paper is used as the fuse train in the ignition system to ensure that all the heat pellets of the cell stack ignite. The material consists of a mixture of fine zirconium metal and barium chromate powder, intimately mixed with glass microfibers, fiberfrax, and asbestos fibers. It can be made as required and, if the amount used is relatively small, it may be made on a laboratory sheet mold. Burning rate and ignition sensitivity tests are sufficient to verify its usefulness.

*Igniter or Electric Match*—The PS413 uses an electric match to ignite the power supply. The match is a welded bridge match with a bridge resistance of 1.3 ± 0.1 ohms. This item is used in several power supplies and can be bought in relatively large quantities. There is, however, another cheaper version, it has been used as a soldered bridge and can be used for experimental as well as routine test power supplies. The bare match can be purchased, and short ribbon leads of steel or nickel can be spot-welded to the match tabs for subsequent connection to the power supply terminals.

*The Can and Lid*—The PS413 can is a drawn steel can and is purchased commercially. It measures 2.160 I.D. and 1.625 in. high, with a wall thickness of 0.035 in. and a bottom thickness of 0.075 in. Cans are ordered in quantity, and for small production runs the entire order is placed

immediately when work is started on the power supply. The PS413 lid has been purchased in two steps. A metal fabricator supplies the lid blanks—a disk of 2.16 in. diameter with four 0.161-in. diameter holes and an indent near the edge for subsequent heliarc welding. The lid or cover blank is sent to another specialist firm for installation of the glass terminal seals and the insulated wire leads. Some terminal seal fabricators will also fabricate the metal piece. The purchaser of both the can and the lid will bear the tooling costs for purchase.

*Thermal and Electrical Insulation*—Usually, the thermal insulation in the thermal power supply can also act as the electrical insulation. The materials used are cloths or papers made of inorganic fibers and phlogopite mica. The asbestos papers come in various thicknesses quantities and are easily made by punching them into cutter disks or other shapes. A problem for people who make asbestos parts is the danger of their breathing asbestos dust. The light fibers and dust may become airborne and become air pollutants. Some thermal power supply manufacturers are now ordering these punched parts from specialty suppliers who presumably have adequately protected their personnel from the dust.

The asbestos papers contain organic binders so they may be handled without tearing. Organic materials will break down in an activated thermal power supply, generating gas, developing high pressures, and causing undesired chemical reactions. Therefore the piece parts of asbestos (and fiberfrax) are oven baked at 1000 F for 30 minutes to drive off such binders. Fiberfrax paper, more fluffy than asbestos, is used as stack-wrapping material. Mica is used to protect leads from very hot or burning surfaces and, since it is an impervious material, it will also protect leads from the possible flow of liquefied electrolyte. It also provides a vapor barrier around terminal seals to prevent vapor formed in the power supply from reaching cooler lid surfaces, condensing, bridging the glass seal insulation, and shorting the leads to the can. Mica, which is expensive, is generally bought from suppliers who fabricate the piece parts. Adhesive and nonadhesive woven glass tape is used to maintain the stack structure integrity by a tight wrapping of the insulations against the stack. The assembled stack, with the cells in the center and each end built up with extra heat pellets and end insulators, is held under pressure in a press while the wraparound and lead insulators are applied. Narrow glass tape is wrapped tightly over the insulators and adhesive is used to prevent unraveling.

*End Collector Plates and Leads*—The end collector plates are disks of 0.005-in. (0.1270 mm) steel with a ribbon iron lead welded to them. The bimetal plates are punched from 0.005-in. strip stack using the ram dies. There are two such plates to each battery, one at each end of the stack. These plates bring the electrical energy out of the stack.

The internal power supply leads are made from the same material. It is purchased as narrow strip stock and cut to the desired lengths.

*Parts Fabrication, Subassemblies, and Final Assembly*—Thermal power supplies have always been basically hand-assembled items, and they have been hand assembled because of their low procurement level. Large procurements would make it economically feasible to mechanize the battery assembly. For instance, both the DEB and heat pellets can be made on an automatic press (14 per minute). But each type of pellet is collected and individually weighed on an automatic laboratory balance and sorted according to the weight range. Each cell stack is built up of hand-transferred parts on an assembly jig. The correct number of piece parts is controlled by laying out each type of part on designated spots on a control card. The stock is then assembled by taking the pieces from the card in consecutive orde

Figure IV-14 shows the movement of material and the operations involved. After the various piece parts have been purchased, made, and assembled, the power supply manufacture involves the fabrication of a number of subassemblies—ideally simultaneously—which are then combined into the power supply. The subassemblies are the cell stack, with associated wraparound insulators and fuze train, the lid assembly; the insulated can assembly, and

the match with leads. From figure IV-14, one can see that the vacuum drying and firing (baking) operations are frequent.

The following piece parts would be made in house with tooling on hand. Dies would have to be fabricated for the pellet press and punch press.

| Item | Stack material | No./power supply | Tool |
|---|---|---|---|
| Anodes | Bimetal (purchased) | 11 | Dies and punch press |
| DEB pellets | DEB powder | 11 | Dies and pellet press |
| Heat pellets | FE heat powder | 8 | Dies and pellet press |
| Fuze train | Zr heat paper slurry | 1 | Sheet mold |

The building of between 500 to 5000 power supplies requires scheduling the purchase of those materials and items obtainable from outside suppliers, in-house preparations of materials and subassemblies, sufficient work space and storage space for those materials and items awaiting further operations, and wise use of available personnel.

### IV-3.3 Support

Items of support for the Power Supply PVF include materials, people, and equipment.

*Materials.*—Typically, items such as the lids and mica require from 6 to 7 weeks lead time. Lead times for many of these special materials vary greatly with the general economy and with specific conditions of supply and demand. However, the entire quantity of DEB powder and heat powder for a lot run may be prepared at the beginning, checked out, pelletized, and stored in sealed containers until needed.

The number of people required at any one time can be kept low if material availability permits optimum scheduling of the work. The same operators who assemble stacks (which takes 10 minutes) can also line cans, assemble lids, etc. The heliarc welding operations to seal the power supply will require a skilled operator. One person can prepare the two powders, but it would be better to have at least two people knowledgable in the operations. Pellet and punch-press operations can be handled by one operator. Chemical and other tests on the electrolyte and heat powders can be performed by chemical laboratory personnel.

The accompanying equipment lists show that much of the equipment presently on hand is applicable to the proposed activity: punch press, hydraulic press, pellet press, spot welder, etc. Most of the required new equipment relates to the powder preparations: an oven, blenders, granulators, etc. However, at least one large vacuum oven will be needed to accommodate the greatly increased volume of material to be vacuum dried at one time.

One area of concern that has been mentioned previously involves dust control. Dusts are generated in both the powder preparation and at the pellet press. The calcium chromate contained in the electrolyte dust is considered carcinogenic and must be contained within a closed system at all times. The thermal power supply industry is now working on this problem, but at the present time has not developed an entirely satisfactory solution.

*Dry room.*—The equipment and materials needed for a dry room are listed below.

Equipment

Stokes granulator, Model 43
Twin shell blender
Microatomizer, type 5MA
Burning rate test equipment
Ignition sensitivity test equipment
Fusion over blue MCFD 20
Fused-quartz trays
Small muller, Simpson
Vacuum oven, Stokes, Model 138D
Bi-metal deposition
Degreaser
Tooling dies for pellet
press stacking

## IV-4. Air-Driven Power Supplies

### *IV-4.1 Background and Introduction*

The current air-driven power supplies being developed for electronic fuzes are small assemblies of mechanical and electromechanical components, designed for eventual high-volume, low-cost production The units are generally less than 1 75 in (~44 mm) in any dimension, may be produced in a volume of more than 50,000 per month, and cost from $1 00 to $3 00 each High-volume production of these units must use fabrication techniques such as stamping, casting, sintering, and molding in combination with mechanized assembly and testing in order to meet the high-volume, low-cost goals

Currently, two basic types of air-driven power supplies lend themselves to high-production prototype validation One device is a turbine/alternator (T/A) for the XM734 multi-option mortar fuze, currently in advanced engineering development (see fig IV-17) The other device is a fluidic generator being developed for use with a 2 75-in rocket fuze (see fig IV-18) This device is in the intermediate stages of development Each type of device contains an electromagnetic circuit and a means for modulating the circuit, which depends on in-flight ram-air flow through the unit

In the case of the T/A ram air enters the device through an intake at the projectile nose and is directed toward a turbine The kinetic energy of the air is converted by the turbine to mechanical-rotational energy, the exhaust air is then expelled through slots uniformly spaced around the circumference of the fuze ogive The rotational motion of the turbine is transferred to a cylindrical permanent magnet rotor by a concentric shaft The rotor turns between the poles of a magnetic stator and induces an electromotive force (emf) in the armature windings

For the fluidic generator (fig IV-18), ram air flows through the generator nozzle and passes into a cavity, causing oscillations in the cavity which induce a mechanical vibration in a metal diaphragm at the rear of the cavity The vibrating diaphragm changes the flux permeance of a magnetic circuit, thus generating an ac signal in the coil windings of the circuit

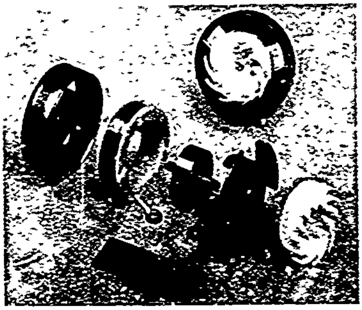


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**Figure IV-17. Turbine alternator for XM734 multi-option mortar fuze.**

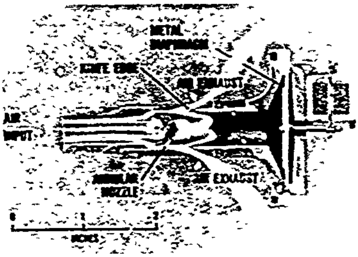


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**Figure IV-18. Fluidic generator for environmental sensor.**

Since the two types of devices are similar, assembly and testing of both types would use similar procedures, thus, much of the same type of assembly and test equipment would be used for validating high production assembly procedures for both devices

### *IV-4.2 Equipment Description*

Required equipment to assemble the air-driven power supplies would be composed of one synchronous assembly machine and three non-synchronous assembly stations. This equipment would allow for validating individual assemblies and would assist in determining the most cost-effective assembly layout required for implementing an automated assembly of an air-driven power supply. The optimum layout would consist of strictly synchronous, nonsynchronous, or a combination of the two types of equipment.

Production assembly processes that might be followed for final assembly of T/A's and fluidic generators are given in two process flow charts, figures IV-19 and -20. The feasibility of the production and process concepts given on the charts has not been verified to date. They reflect assembly procedures that would be required for the power supplies in their current states of development.

The current T/A has been designed to be amenable to high-volume production. The flow chart for this design is therefore quite representative of advanced engineering planning. Assembly of this type of power supply will be discussed in detail station by station as described in appendix IV-A.

The assembly equipment discussed here is nonsynchronous. A system employing this type of equipment consists of a series of assembly stations. Part transfer between machines would be performed by an operator. This type of system allows each station to work independently, at its optimum cycle rate.

A typical flow chart of assembly stations to implement the mechanized assembly of the current low-cost T/A for the XM734 fuze is described in appendix IV-A and in figures IV-21 and -22.

Components of the facility used for assembling T/A-type power supplies could be retooled and employed in assembling fluidic generator-type power supplies.

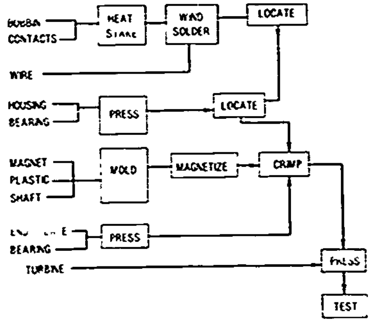


Figure IV-19. Turbine alternator process flow chart.

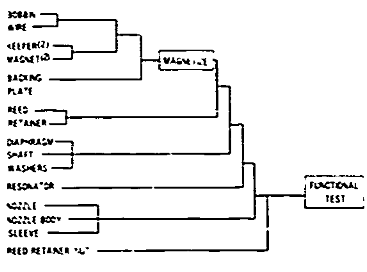


Figure IV-20. Fluidic generator process flow chart.

The use of toolable assembly stations, which permits individual development of assembly stations, creates a need for only one or two assembly machines to validate all the assembly operations. Each individual operation could be developed, debugged, and optimized station by station.

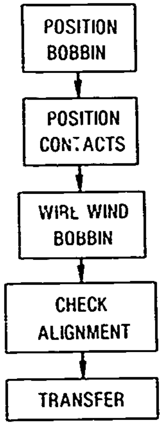


Figure IV-21. Bobbin assembly.

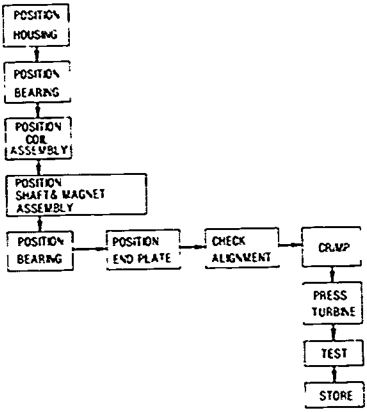


Figure IV-22. Turbine alternator assembly.

## Appendix IV-A.—Production-Line Handling Methods

### IV-A.1 Aqueous Power Supplies

#### *IV-A.1.1 Sequence of Operation*

A description of the station sequence of assembling aqueous power supplies follows

1 The weight is transported, by vibratory bowl feeding, to an escapement which drops an individual weight into an awaiting workholder, contained in a six-station, intermittent-motion dial

2 The dial then conveys the weight to the cartridge placement station. The cartridge assembly consists of an inner cup, a wad of polypropylene fiber, and an outer cup. The cartridge cups will be fabricated in house with forming and blanking of these parts, from coil stock, taking place in progressive dies at a rate of 100 parts per minute Two die sets will be required, one each for the inner and outer cups The die sets will be individually operated by an in-house 30-ton Minster press Following blanking, both inner and outer cartridge cups will be vapor degreased to remove die lubricants to assure maximum cleanliness Polypropylene fiber will be purchased in mat form Because of the recuperative properties of polypropylene fiber following blanking, it is imperative that this material be contained until it is encapsulated between the two cups Cartridge assembly is performed in a vertical, four-station, intermittent motion dial.

3 The dial then indexes, conveying the weight and its cartridge assembly to the ampule can placement station

4 An ampule can from a vibratory bowl is transported (flange down) to an escapement which drops it over the awaiting weight The ampule can will be fabricated in house in progressive forming and blanking at a rate of 100 parts per minute The ampule can die set will be operated, interchangeably, in the same press used for production of cartridge cups. To assure optimum cleanliness, ampule cans will be vapor degreased, to remove die lubricants, immediately following blanking

5 The dial indexes the ampule can assembly to the ejection station During indexing, a pin in the bottom of the dial's workholder raises the assembly for ejection

6 The ampule can assembly, ejected to an inverting track, is ejected to an accumulation dial During its travel through this track, the ampule can assembly is inverted (flange now up ), and its contained cartridge assembly moves smoothly to the ampule can bottom At this juncture, the PVF will use tote trays instead of a conveyor system to transport the items to the individual stations for completion of assembly and sealing of the ampule

7 At the methylene bromide injection station, a vacuum is pulled on the ampule can interior, and the methylene bromide is injected into the awaiting ampule assembly, with a metering pump controlling the volume

8 At the cutter assembly station, a cutter assembly is transported to an escapement by a vibratory bowl and is dropped into an awaiting ampule can assembly The cutter's design renders it prone to interlocking jams during vibratory conveyance This problem will have to be resolved in the PVF

9 At the fluoboric acid injection station, a dispensing nozzle advances and lowers the ampule can The electrolyte is injected into the ampule can assembly with a metering pump that controls volume A lead is ' by hand onto the ampule and clamped until the ampule is welded

10 The diaphragm will be fabricated in house from raw materials Coil stock will be fed through a strip degreaser to assure component cleanliness, then blanked into storage tubes A 4-ton hydraulic press will be used in conjunction with a 2-on die set, operating lubricant free Total output anticipated, is 200 parts per minute (press speed 100 strokes per minute)

11 Upon arrival at the welding station, a stepping motor engages the workholder rotation gear The workholder rotates, TIG welding is activated, the diaphragm is welded to the ampule can flange around the entire circumference with overlap as required When TIG welding deactivates, the stepping motor disengages and the rotating workholder deactivates

12 The ampule assemblies will now be placed in an oven on acid-detecting paper and heated to 200 F for 24 hours, at the end of which time defective units will be noted. Weights and cutter assemblies will be salvaged before the ampules are discarded

### *IV-A.1.2 Cartridge Assembly (fig. IV-A-1 and - 2)*

An inner cup from a vibratory bowl is lightly pressed into an awaiting hold in the vertical dial by a placement punch The inner cup placement punch retracts, the vertical dial indexes, conveying the inner cup to the polypropylene fiber placement station Then the polypropylene fiber, either automatically or manually fed, is blanked through a die and placed in the hole in the vertical hole on top of the inner cup, the polypropylene fiber blanking punch retracts, and the vertical dial indexes, conveying the inner cup and polypropylene fiber to the outer cup placement station. An outer cup from a vibratory bowl is lightly pressed and inverted into the counterbored dial hole containing the previously placed polypropylene fiber and inner cup and outer cup The outer cup placement punch retracts The dial-mounted assembly punch retracts to its

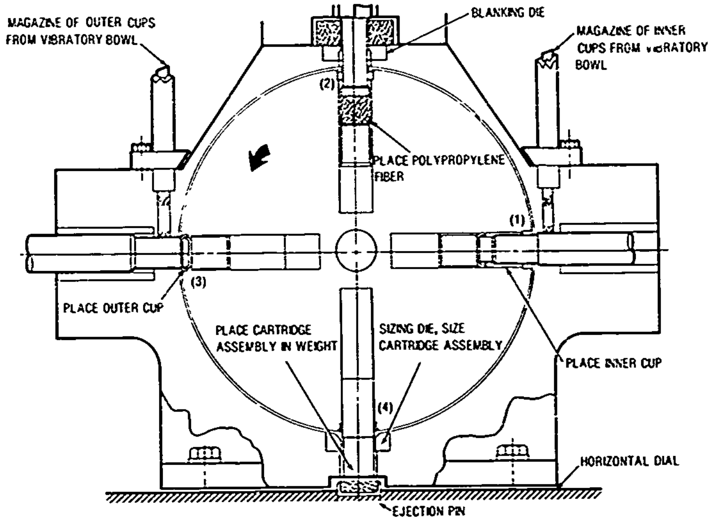


**Figure IV-A-1. Mechanized cartridge assembly.**

point of origin The vertical dial indexes, conveying the assembly to the cartridge assembly placement station The assembly punch in the vertical dial advances, pressing the cartridge assembly through a sizing die and into the weight in the horizontal dial

### *IV-A.1.3 Cutter Assembly (fig. IV-5 through IV-7, main report)*

The sequence for cutter assembly follows

1 Three pickup pins, mounted in workholders in the intermittent dial, raise and engage three holes in the cutter plate stock web

2 The cutter plate is blanked and the pickup pins retracting in unison with the blanking die set, position the cutter plate on the dial workholder

3 The die set retracts

4 The intermittent dial indexes, transporting a cutter plate to station 2, the cutter plate placement position The cutter plate stock web advances

5 At station 2, a cutter blade from a vibratory bowl is placed on the awaiting cutter plate hinge and crimped in position

6 Placement is performed by "pick-and-place equipment which in the PVF application would likely be done by hand

7 With the intermittent dial stationary, the dial workholder indexes 120 deg

8 Repeat step 5

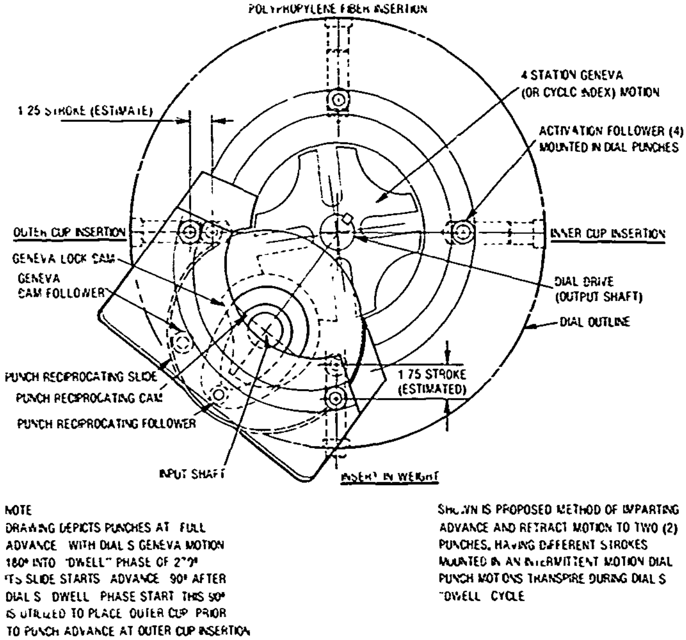


**Figure IV-A-2. Polypropylene fiber insertion.**

9 Repeat step 6

10 Repeat step 7

11 Repeat step 5

12 The intermittent dial indexes, conveying the cutter assembly to station 3

13 At station 3, a compression mandrel lowers, retaining the cutter assembly under compression on the dial workholder

14 The cutter plate hinge-forming punch raises from the dial workholder, forming the three cutter blade retaining hinges of the cutter plate (fig IV-8, main report)

15 The compression mandrel retracts

16 The cutter plate hinge-forming punch retracts

17 The intermittent dial indexes to station 4

### *IV-A.1.4 Electrode and Ampule Assembly Line (fig. IV-1, -9, -10, main Chapter)*

At station 1, the insulator (fig IV-1) is placed in the workholder by an automatic placing mechanism In the following assembly procedures all fabricated parts except the sequencer and the

ampule assembly, will be supplied to the placing mechanisms from magazines

At station 2, the bottom plate is automatically placed in the workholder for production

At station 3, seven stacking mechanisms will be used Each mechanism will alternately place 20 separators and plates For the PVF, one mechanism will be used

At station 4, the sequencer is placed onto the stacks This will be done by a vibratory bowl feeder and automatic placing mechanism

At station 5, the seal ring is automatically placed on top of the sequencer

At station 6, the ampule assembly will be placed automatically Ampule assemblies will be supplied on trays and fed into the placing mechanism by a vibrator

At station 7, a compression guard, fed by a vibratory bowl, will be placed onto the assembly This reusable guard will protect the edge of the ampule as well as provide even force distribution during compression

Station 8 will not be used for the PVF In the production line, this is an inspection station where automatic equipment checks the proper placement of sequencer, seal ring, ampule, and compression guard

### *IV-A.1.5 Compression and Heat Seal (fig. IV-9, 11, main Chapter)*

The compression and heat seal operations follow

1 A ram lowers and cocks the spring in the workholder, applying 250 lb of pressure on the electrode and ampule assembly

2 The induction coils lower, heat the assembly to 300 F, and retract

3 Two locking dogs are advanced onto the unit compression guard

4 After the locking dogs are in place, the ram retracts This completes the cycle, and the workholder is removed

At station 10, the workholders are passed through a cooling tunnel

At station 11, electrode and ampule assemblies are removed and the workholders are reset for recycling through the system The unloaded assemblies will be visually inspected and manually transferred to station 12

### IV-A.2 Air-Driven Power Supplies

### *IV-A.2.1 Mechanized Assembly (Turbine/Alternator*

The shaft and magnet assembly would be performed in an injection-molding machine A shaft would be positioned within the center hole of a magnet, and the plastic molding compound would be injected between the shaft and the magnet

The coil assembly would consist of sequentially assembling the following parts bobbin, contacts, and wire After a check to ensure that the assembly is complete, the unit would be removed from the coil assembly machine and carried to the final assembly machine The station-by-station final assembly operations are detailed as follows

*Station 1*—Feed bobbin, orient, pick up, and place in nest on pallet

*Station 2*—Feed contact, orient, pick up, and place over ports on bobbin, heat stake ports.

*Station 3*—Same as station 2, except contact is placed at second contact location

*Station 4*—Wrap one end of wire to one contact, wind required number of turns around

bobbin, and attach other end of wire to other contact

*Station 5*—Sense presence of parts by continuity check, lift assembly from pallet, and discharge into container

The following parts are sequentially assembled to make the basic turbine/alternator assembly housing, bearing, coil assembly, shaft and magnet assembly, bearing, and end plate After a check to ensure that the assembly is complete, the housing is crimped to complete the assembly The turbine is then press-fit on the alternator shaft, and the T/A is functionally tested The unit is then degaussed, if required, to assure proper operation The station-by-station assembly operations are detailed as follows

*Station 1*—Feed housing, orient pick up and place in next position on pallet

*Station 2*—Feed a bearing, pick up, and place in boss in housing

*Station 3*—Feed coil assembly, orient, pick up, and place in housing

*Station 4*—Feed shaft and magnet assembly, pick up, and place in bearing in housing

*Station 5*—Feed bearing, pick up, and place on front end of shaft

*Station 6*—Feed end plate, orient pick up, and place over bearing and into housing

*Station 7*—Sense for presence of housing, bobbin, shaft, and end plate

*Station 8*—Crimp end plate to housing

*Station 9*—Feed turbine, orient, pick up, and press onto shaft

*Station 10*—Test and degauss T/A assembly.

*Station 11*—Remove T/A assembly from pallet and relocate in compartment trays on an X-Y indexing container

# Chapter V.—Printed-Wiring Board Fabrication

by Ira Marcus

## V-1. Introduction

A survey of the fuze designers at HDL and a study of published articles concerning circuit fabrication techniques of the future indicate that the printed-wiring board (PWB) will continue to be a major component in the construction of commercial and military electronics. The reasons for this follow. (Pertinent literature is listed in the Selected Bibliography at the end of this Chapter.)

1. Low cost. PWBs are relatively inexpensive. To a large degree, board cost is related to area. In fuzing applications the areas of the patterns are small: in mortar and artillery applications, they range from less than 1 in$^2$ to 5 in$^2$. Nevertheless, the fuze boards are produced in large quantities by the processing of arrays of individual boards on large sheets—the boards are cut apart and are easily shaped to the irregular geometry of fuzing applications. An additional advantage is that they do not use precious metals.

2. Ruggedness. PWBs have successfully been used in mortars and in artillery and ground equipment under the most severe circumstances of shock, vibration, and temperature extremes. They can accommodate all anticipated fuzing applications.

3. Greater use. As applications become increasingly complex and the technology of multilayer PWB's matures, we can expect greater use of small multilayer boards in low-cost, high-volume ordnance electronics.

4. Versatility. PWB construction techniques are ideal for the small size of proximity fuze antennas and rf stripline circuitry. Use of the PWB process for these applications, however, requires greater precision and more refined processing control than normally needed to fabricate PWBs for interconnection. At high frequencies, PWB techniques also permit fabrication of capacitors and inductors in addition to the simple conductor pattern.

Where space is severely restricted, thick and thin film fabrication techniques offer some advantages. Those processes allow fine line definition and printing or deposition of resistors. Both thick and thin film techniques also offer some limited capacitor fabrication. However, many applications do exist in which a large available volume allows the use of the more rugged PWB. Some work is now also being done to explore the printing of low temperature-curing resistor material onto PWBs that will be competitive with the ceramic-based circuits.

The major problems that would be addressed by the Printed Wiring Board Fabrication Facility are

(a) Process selection for fabrication of PWBs which optimize desired electrical characteristics (such as antennas, rf boards, filters, and microwave circuits)

(b) Producibility of all board designs by production equipment

(c) Comparison and evaluation of existing processes

(d) Evaluation of new processes

(e) Development of new processes and materials through Manufacturing Methods and Technology (MM&T) studies

## V-2. Types and Processes for Fabricating PWBs

There are several types of PWBs and several ways to fabricate them.

## Types of PWBs

*Single sided* A PWB whose insulating substrate has a conductor pattern on only one of its surfaces

*Double sided* A PWB whose insulating substrate has conductor patterns on both of its surfaces Desired connections between patterns on both sides may be made by component leads, wires, rivets, and by plating through

*Multilayer PWB* In complex electronic arrays where even a double-sided PWB is not enough to solve the interconnection topological problem, it is necessary to use additional layers of PWBs The multiple boards are made into a laminar stock of insulated thin PWBs interconnected by plated-through holes The multiple layers and plating-through techniques allow topological solutions between any of the boards and eliminate the need for jumper wires A multilayer PWB consists of several layers of separate circuits bonded together to produce a thin homogeneous unit with internal and external connections to each level of the circuitry as dictated by the electrical requirements of the system This ability to provide 'stacked' or three-dimensional circuitry offers a number of unique advantages to the electronic packaging engineer in areas where volume reduction is as important as the requirement for special electrical characteristics Three basic methods are used to interconnect multilayer circuits the plated-through hole the clearance hole and the built-up technique The plated-through type provides interconnection to and between layers by a hole which is plated with a conductive material The clearance-hole type provides access to terminal pads on each level of circuitry by clearance holes on each layer above it The built-up process achieves the interlayer connections by sequential metal deposition of conductive patterns with or without the need for holes through the entire thickness of the multilayer board

## Fabrication Processes

*Pattern plating* Only the desired conductor pattern and holes (plated-through) receive metal buildup before etching of the pattern See figures V-1 and V-2

*Panel plating* The entire surface and holes (plated-through) receive metal buildup before etching of the pattern See figures V 1 and V-2

*Etched process (subtractive)* The process begins with a substrate which is covered with copper on one or both surfaces, metal is selectively added and then removed by etching to form the desired pattern See figures V-1 and V-2

*Additive Process* The process which begins with a substrate having no copper on either surface and has the metal pattern selectively added to it See figures V-3 and V-4

## V-3. Process Capability of PWB Facility

The type of PVF needed for PWB fabrication would be able to fabricate single-sided, double-sided, and multilayer PWBs using both the additive and subtractive processes The subtractive process allows both pattern and panel plating The additive process uses only pattern plating The various combinations used in the fabrication of PWBs have different advantages Since the equipment to produce any one type of board can be used to fabricate any other type of board by change of chemicals and processes, few additional costs are incurred for this versatility. Of course, the multilayer PWB does require use of a laminating press. However, the anticipated need for multilayer PWBs in future fuzing applications is high, and this special press is warranted

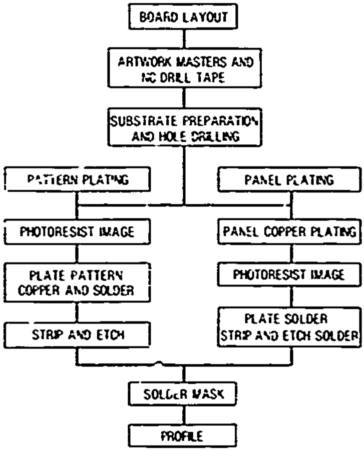


Figure V-1. General flow chart for subtractive process.

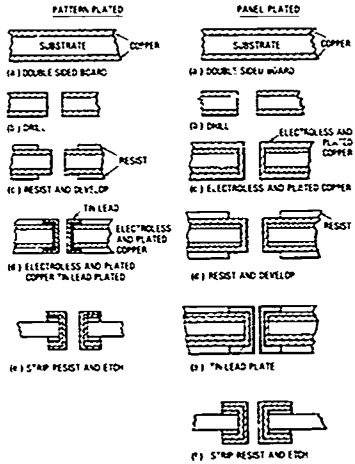


Figure V-2. Plated-through holes.

## V-4. Detailed Description of PWB Facility

### *V-4.1 Artwork Master Generation and Numerically Controlled Drill Tape Preparation*

The first steps in the PWB design process will be completed in the existing laboratory area. Adequate computer-based facilities for master artwork generation and numerically controlled (NC) drill tape preparation already are available. One-to-one step and repeat negative and compatible NC drill tapes will be provided by existing personnel in the laboratory. In those cases where artwork masters are provided but are not accompanied by NC tapes, the PVF NC drill will be able to cut its own control tape. The existing artwork master generation equipment consists of

(a) Reduction camera (see fig. V-5) 42 x 42-in copy board

(b) Step and repeat automatic camera (see fig. V-6)

(c) Printed wiring board artwork generator (see fig. V-7) 16 x 20-in photoplotter
Two interactive cathode ray tube (CRT) design stations
Two large interactive plotting surfaces
Magnetic and paper-tape input and output
Software to provide drill tapes

(d) Complete photographic processing system

A one-to-one step and repeat phototool and NC drill tape will be output by the above equipment and delivered to the PVF.

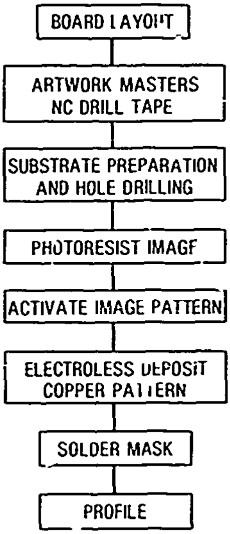


Figure V-3. General flow chart for additive process.

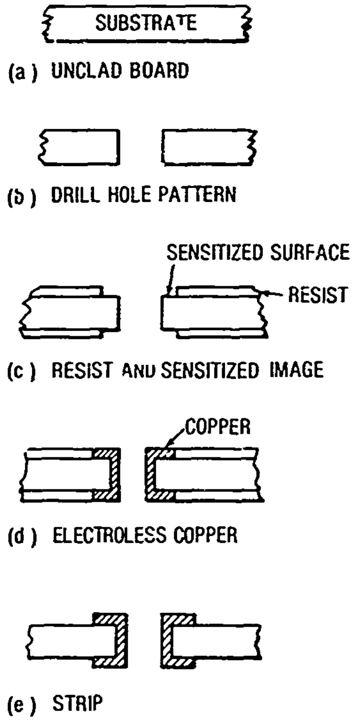


Figure V-4. Additive process.

*V-4.2 Substrate Preparation and Hole Drilling*

Raw substrate stock will be purchased in the commercially available 3- x 4-ft size. The stock will be cut to the basic handling panel size by a 36-in shear. The panels are then punched for registration with two locating holes. Pattern hole forming is accomplished by either NC drilling with a multi-spindle drill or by punching with a 35-ton press. The panel is then degreased and scrubbed.

*V-4.3 Photoresist Imaging*

Depending upon the application, a specific sequence of photoresisting, exposing, and developing is required. When dry film is used, the film will be applied with a laminator, exposed with ultraviolet light, and spray developed. Less accurate resist patterns will be screen printed on the panel. An oven is required to cure certain types of resist.

*V-4.4 Board Pattern Processing*

Equipment is required for processing-board patterns using both the subtractive and additive processes. The subtractive process requires a conveyor etcher and a series of processing tanks to

221–72

Figure V-5. Reduction camera.

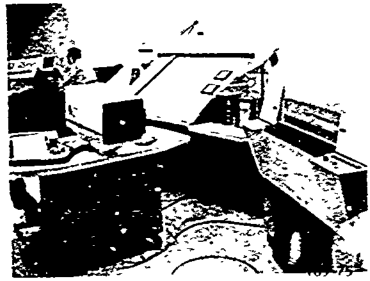

Figure V-7. Printed-wiring board artwork generator.

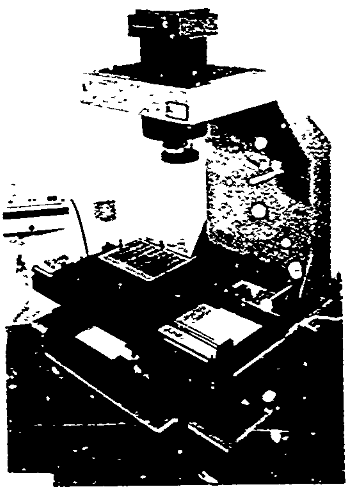

Figure V-6. Step-and-repeat automatic camera.

electroless plate copper, electroplate copper, and to electroplate tin-lead A solder reflow furnace is required to seal the walls of the pattern, to remove slivers, and to improve solderability after storage The additive process requires only a series of processing tanks A laminating press is needed to compress and bond the layers of a multi-layer stack

Board profiling is to be done for complex shapes by a 35-ton punch press while simpler shapes will be template sheared in a hydraulic press

### V-4.5 Board Inspection

The inspection area will house the plating area calculator, which determines the plating power supply settings A plating thickness gauge and lead-tin percentage analyzer will confirm the plated thickness and composition of the deposited solder A large-field optical comparator will examine hole quality and allow precision measurements of trace width, hole size, and spacings

Table V-1 lists the equipment and utilities needed for printed-wiring board fabrication. Figures V-8 through V-21 show the type of equipment needed

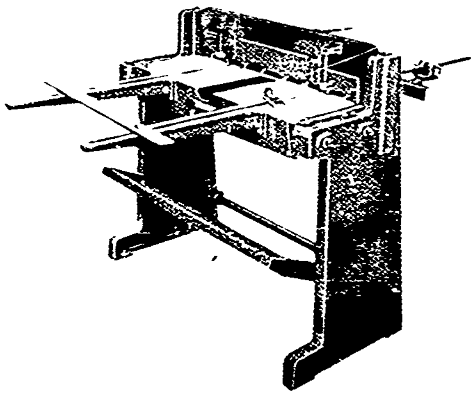

Figure V-8  A 36-in. shear.

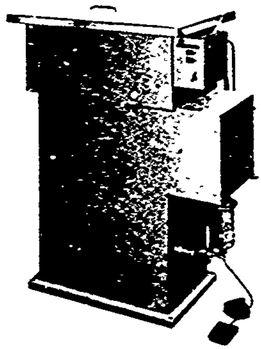

Figure V-10. Degreaser.

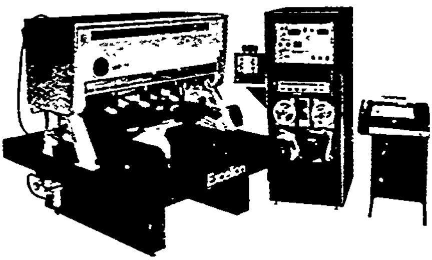


Figure V-9. NC drill.

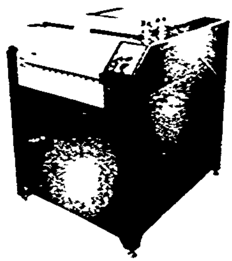

Figure V-11. Printed-wiring board/
scrubber.

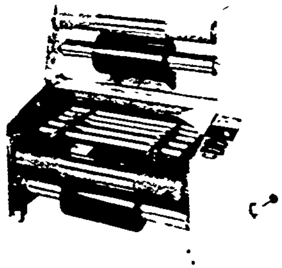

Figure V-12. Dry film laminator.

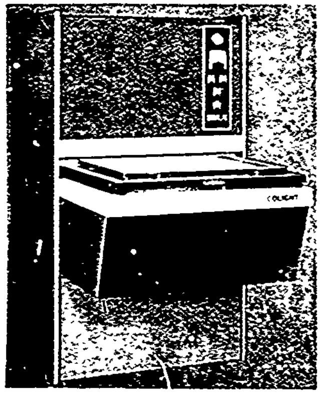

Figure V-14. Ultraviolet exposer.

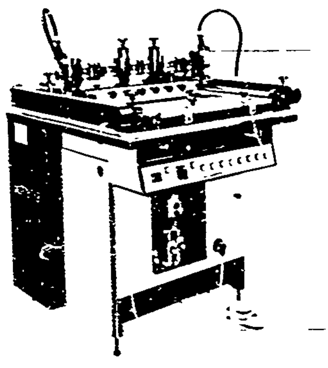

Figure V-13. Screen printer.

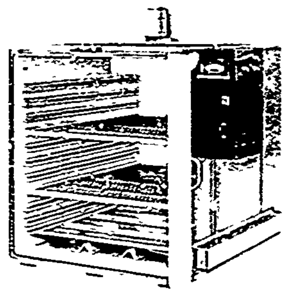

Figure V-15. Oven.

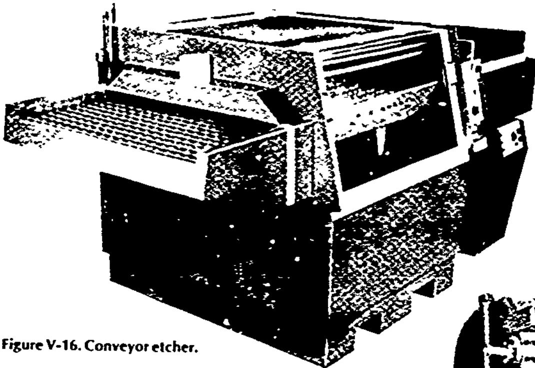

Figure V-16. Conveyor etcher.

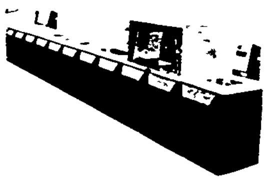

Figure V-17. Subtractive process line.

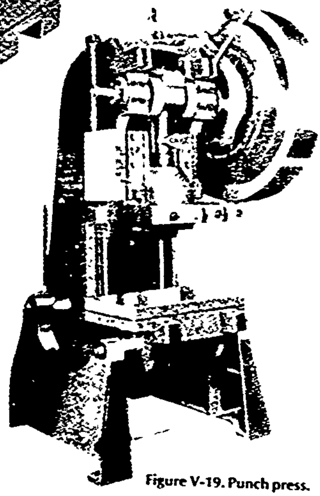

Figure V-19. Punch press.

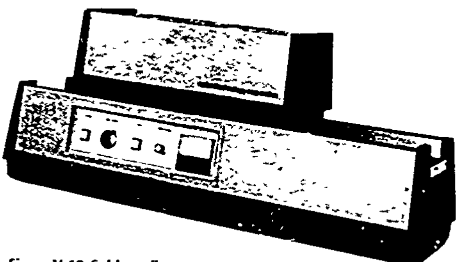

Figure V-18 Solder reflow.

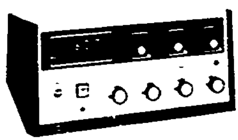

Figure V-20. Plating thickness measurement.

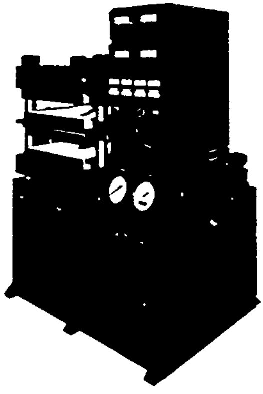

Figure V-21. Multilayer press.

Table V-1 Equipment and Utilities Needed for Printed Wiring Board Fabrication

| Process/equipment | Utilities |
|---|---|
| *Substrate preparation and hole drilling* | |
| 36-in. shear | Compressed air 100 psi |
| NC drill | Compressed air 100 psi 208 V 3 phase |
| Registration punches | None |
| Degreaser | 208 V 3 phase fume exhaust |
| Printed-circuit scrubber | 208 V 3 phase cold water drain |
| *Photoresist imaging* | |
| Dry film laminator | 208 V single phase fume exhaust |
| Developer | 115 V single phase fume exhaust, cold water drain |
| Screen printer | 208 V 3 phase |
| UV exposer | Fume exhaust, 208 V single phase |
| Oven | 208 V single phase |
| *Board Processing* | |
| Conveyor etcher | 208 V 3 phase cold water drain, fume exhaust |

Table V-1 (cont'd) Equipment and Utilities Needed for Printed Wiring Board Fabrication

| Process/equipment | Utilities |
|---|---|
| *Board Processing (cont'd)* | |
| Additive process | Cold water, drain, 115-V single phase fume exhaust |
| Subtractive process | Cold water hot water drain, 208 V 3 phase compressed air (100 psi) fume exhaust |
| Multilayer press | 208 V 3 phase cold water drain compressed air (100 psi) |
| Solder reflow | 208 V 3 phase fume exhaust |
| Punch press 35 T | 208 V 3 phase compressed air (100 psi) |
| Hydraulic press 6 T | 208 V 3 phase |
| *Inspection* | |
| Plating thickness measurement | 115 V single phase |
| Plating area calculator | 115 V single phase |
| Other inspection aids | — |
| *Miscellaneous* | |
| Storage | — |
| Chemical recycling | — |
| Sinks benches | — |

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## Chapter VI.—Electronic Board Assembly Facility

by Ira Marcus

### VI-1. Introduction

Electronic components will be assembled onto printed-wiring boards by hand or by machine, or by both Certain fuze designs are so densely packed that it is not possible to insert parts by machine For those cases, the Electronic Board Assembly Facility (EBAF) will provide for modern assembly-line fabrication by hand, using programmed conveyor-connected stations and in line inspection Those circuits which will allow machine insertion of parts will be fabricated that way

One of the primary objectives of the EBAF will be to explore all possible means of machine insertion assembly In those instances where it cannot be done, the objective will be to efficiently use hand assembly in conjunction with other semiautomatic methods In both cases, the subsequent soldering operation will be done by use of mass soldering equipment Lead trimming will be done by an automatic lead cutter During various states of fabrication, from subassembly to the almost completed fuze package, it is sometimes necessary to encapsulate sections of electronics The EBAF will be able to pot electronics using both the solid epoxy-type and foam encapsulants Some of the benefits of this section of the PVF would be to

(a) demonstrate that a particular assembly can be fabricated with automatic equipment

(b) allow precise production cost estimates of specific circuit designs

(c) prove out the capability of circuit components to be mass soldered

(d) prove out the mass solderability of etched-wire board layouts supporting electronic components

(e) demonstrate automatic lead cutting and isolate problem components whose leads are not suitable for mass trimming

(f) optimize encapsulating design strategy

(g) provide equipment and capability to evaluate the relative cost-effectiveness assembly metnods versus standard hand or standard automatic fabrication

(h) prove out automated or mechanized inspection equipment

(i) provide potential for improving data collection and utilization

(j) prove out the in-line electronic and mechanical equipment required to make final adjustments on the printed-wiring boards

### VI-2. Process Capability of Electronic Board Assembly Facility

The combined abilities of hand assembly and automatic insertion will allow the producibility validation of any envisioned high-volume, ordnance electronics Special machinery can be added as these processes become accepted throughout the electronics industry and the military community. It is expected that integrated circuit packaging will change from individual packages to some form of continuous-roll film mounting for more economical insertion Provision is made for acquiring one such machine As the facility matures, it is expected to be a vehicle for the evaluation of new production machines and processes which could benefit the manufacturing of fuzes. Both in-line and finished assembly testing will be done in the test area Figure VI-1 is a work flow diagram planned for this facility Table VI-1 lists the major equipment required

Some pertinent literature is listed in the Selected Bibliography at the end of this chapter

Figures VI-2 through VI-11 show typical pieces of equipment needed for the electronic board assembly facility

Table VI-1 Printed Wiring Board Assembly Equipment

| Equipment | Utilities |
| --- | --- |
| Ten station programmed assembly bench | 115 V 100 psi air |
| Mass solder | 208 V single phase 100 psi air |
| Defluxer | 208 V three phase fume exhaust |
| Lead cutter | 208 V three phase |
| Curing oven | 470 V three phase |
| Foam potting | 208 V single phase 100 psi air |
| Epoxy dispenser | 115 V 100 psi air |
| Automatic component insertion | 115 V 100 psi air |
| Automatic dip insertion | 115 V 100 psi air |
| Sequencer | 115 V |
| Pantograph insertion | 115 V 100 psi air |
| Parts storage | — |
| Hand tools—assembly | — |
| Rework tools | — |
| Advanced automatic insertion | — |

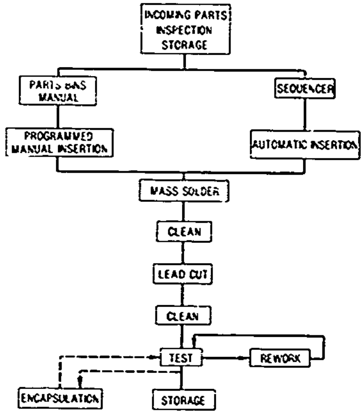


Figure VI-1. Electronic board assembly facility.

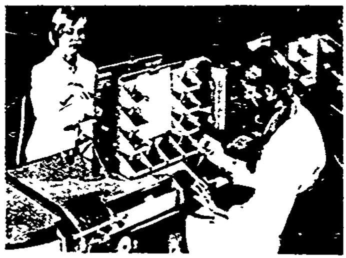

Figure VI-2. Programmed assembly bench.

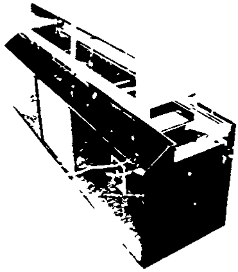

Figure VI-3. Mass soldering machine.

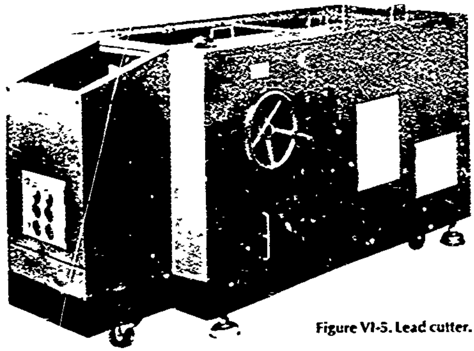

Figure VI-5. Lead cutter.

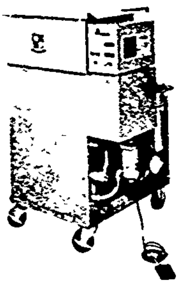

Figure VI-4. Defluxer.

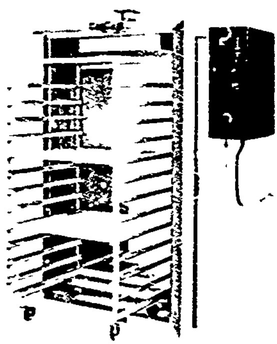

Figure VI-6. Curing oven.

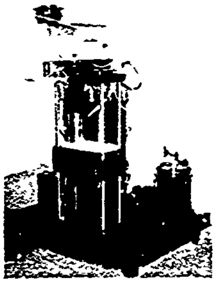

Figure VI-7. Epoxy dispenser.

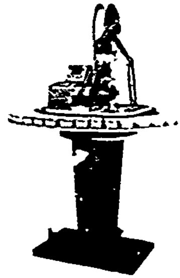

Figure VI-10. Sequencer.

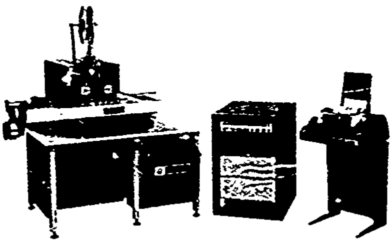

Figure VI-8. Automatic component insertion.

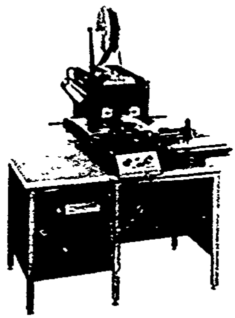

Figure VI-11. Pantograph.

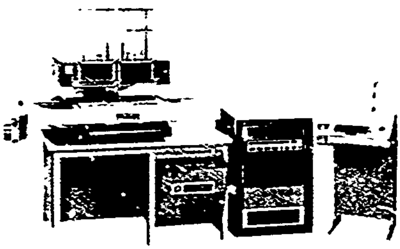

Figure VI-9. Automatic dip insertion.

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## Chapter VII.—Thick Film Hybrid Microelectronic Fabrication and Assembly

by Joseph L. Ansell

### VII-1. Introduction

During the past decade, the production of commercial electronic devices has gradually evolved away from the use of discrete assembly methods toward greater use of hybrid fabrication techniques. In the same time period ordnance fuze technology has seen the replacement of many mechanical and electromechanical fuzes by improved electronic versions: the transistor replaced the vacuum tube, the integrated circuit is replacing the transistor, and state-of-the-art fuzes are increasingly being designed around digital integrated circuits. The complexity of these electronic modules, combined with the small volume available to contain them, has forced ordnance electronic designers toward widespread use of thick film hybrid microelectronics as the fabrication medium for these circuits. All indications are that, in the foreseeable future, hybrid circuits will be a major technology used to fabricate high-volume, low-cost, small-size ordnance electronics.

HDL has been directly involved with modern thick film applications since 1968. The use of this technology has increased greatly since that time as its advantages became known and accepted. One example of its use is in the M734 multi-option mortar fuze, which utilizes thick film hybrid modules for both the amplifier (fig. VII-1) and oscillator circuits (fig. VII-2). As our use of and expertise in thick film hybrid microcircuits have developed, the applications of this technology to fuze designs have progressed from research and development to present involvement with production-based designs. Pertinent literature is presented in the Selected Bibliography at the end of this Chapter.

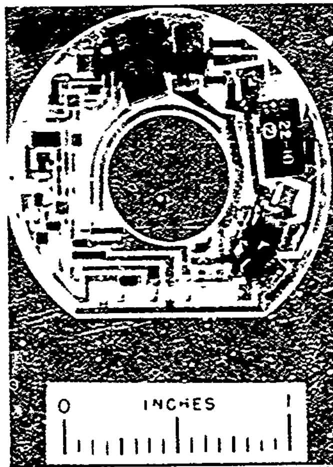


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**Figure VII-1. M734 multi-option mortar fuze amplifier.**

The design of hybrid circuits for production introduces differences in design philosophy, approach, and methods from those previously used in research and development applications.

The thick film group at HDL presently supports both research and development and production-based projects. Development work performed for the latter usually includes initial thick film hybrid layouts as well as prototype samples (in quantities up to about 500), used to prove system

feasibility. In addition, accompanying technical data packages have been prepared.

Due to limitations of the processing equipment currently being used for thick film fabrication, the production data package obtained from prototype samples is not sufficiently accurate. Other problems are also caused by the equipment and techniques, since they are not compatible for the fabrication of small volumes at high production rates. Problem areas are substrate shape, size and orientation of resistors, high-rate wire bonding on small geometries, and final protective circuit encapsulation. During prototype construction, these problems may be solved by careful assembly and detailed inspection by skilled technicians. This

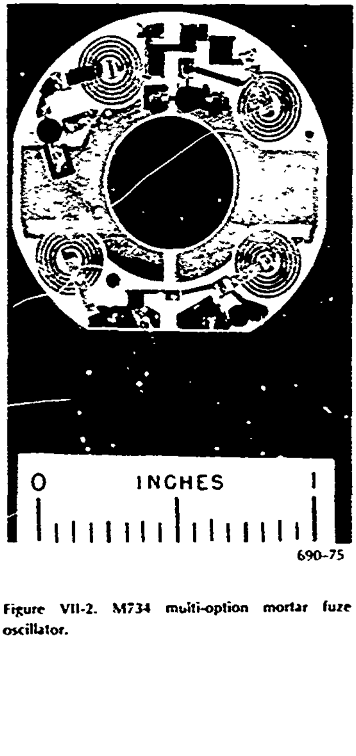


**Figure VII-2. M734 multi-option mortar fuze oscillator.**

would not be economically feasible on an automated, high-volume production line.

With a PVF however, the facilities would be available for determination of proper fabrication techniques of thick film hybrid circuits at high-volume production rates. The experience and knowledge accumulated on this equipment in developing thick film processing techniques and parameters will ultimately provide accurate thick film hybrid microcircuit models that will introduce industry production processes or be compatible with them.

The most important problems that the thick film PVF will attempt to solve immediately are

(a) determination of high-volume production printing parameters for fine-line conductor patterns,

(b) evaluation of print and fire parameters to achieve minimal resistor trimming,

(c) adaptation of functional (active) resistor trimming, compatible with high production rates (this is important in setting burst heights of proximity fuzes),

(d) introduction of automatic wire bonding of all transistors and diodes in hybrid circuits with a single visual alignment, and

(e) development of high-volume, low-cost packaging techniques for the ordnance environment.

## VII-2. Thick Film Process

Thick film hybrid production techniques allow the manufacture of conductors, resistors, capacitors, inductors, and crossovers from thick film materials. All are easily fabricated, and each type of thick film component has its inherent advantages and disadvantages relative to its more standard counterpart. Thick film resistors provide an excellent compromise between conventional carbon composition resistors and metal film types so far as cost, stability, temperature coefficients, and other

pertinent factors are concerned. Thick film capacitors may be fabricated for low values of capacitance. These values are generally limited by the available substrate area. Dissipation factors, however, are usually not as good, and tolerances cannot be held precisely. This may be compensated for by trimming capacitors to value. This process is still being developed for good yields at high production rates and currently has many problems. Inductors may be made with thick film materials by spiralling conductors of narrow line width and varied spacing, but are generally limited to low-inductance, low-Q applications.

The inherent versatility of thick film networks can be extended with the use of dielectrics to provide multilayered circuitry.

Since an introduction has now been given to items that can be fabricated with thick film technology, a simple flow chart (fig. VII-3) will illustrate the ordered steps in making these items. Blocks and paths that are shown as dotted are optional depending upon the requirements of each particular circuit.

## VII-3. Description of Thick Film Facility

The thick film hybrid facility will be divided into several functional areas, described below. Necessary equipment is listed in table VII-1 and shown in figures VII-4 through VII-21 (following chapter text).

(1) *Quality Assurance, Incoming Inspection.* Parts and materials received in the facility will

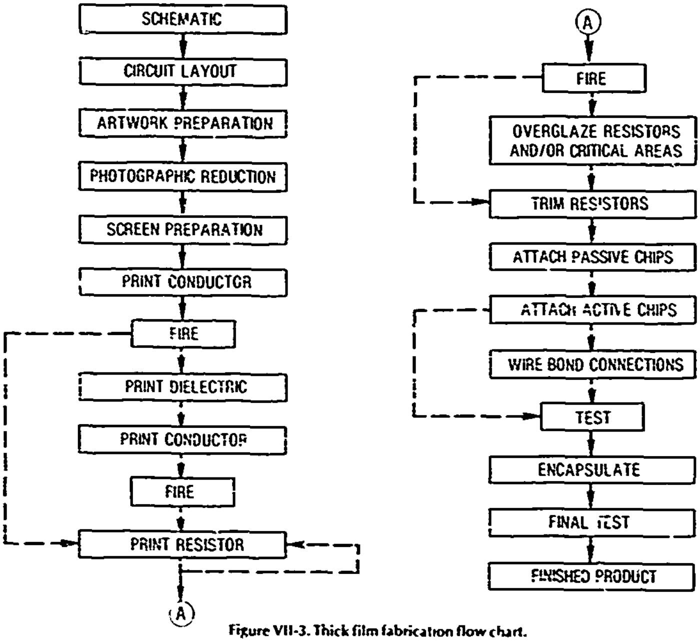


**Figure VII-3. Thick film fabrication flow chart.**

Table VII-1. Equipment Requirements

| Process | Capacity | Utilities |
|---|---|---|
| *Quality Assurance* | | |
| *Incoming Inspection* | | |
| Viscometer | — | 115 V, single phase |
| Microscope, stereozoom | — | 115 V, single phase |
| Microscope, metallurgical | — | 115 V, single phase |
| Epoxy bonder | — | 115 V, single phase, |
| Curve tracer | — | 115 V, single phase |
| Probe station | — | — |
| Printer | — | 115 V, single phase |
| Furnace | — | 460 V, 3 phase, air, 30 psi, cold water, drain, exhaust |
| Digital multimeter | — | 115 V, single phase |
| *Storage* | | |
| Jar roller (4) | — | 115 V, single phase |
| Dessicator cabinet (2) | — | — |
| Large storage cabinets | — | — |
| Screen storage cabinets | — | — |
| Drafting table/desk combination | — | 115 V, single phase |
| Polar coordinatograph | — | 115 V, single phase |
| *Print and fire* | | |
| Printer (2) | 3000 parts/hr each | 115 V, single phase, air, 90 psi, vacuum, 25 in |
| Dryer (2) | — | — |
| Furnace (2) | 5000 1 x 1 in substrates/hr each | 460 V, 3 phase, air, 30 psi, water, drain |
| *Resistor trimming* | | |
| Laser trimmer | 22,000 resistors/hr | 220 V, single phase, 115 V, single phase, air, 80 psi water, drain |
| *Passive assembly* | | |
| Edge pin attach | — | 115 V, single phase |
| Robot parts placer | 1800 chips/hr | 115 V, single phase |
| Solder reflow | 600 1 x 1 in substrates/min | 115 V, single phase |

Table VII-1 (cont'd). Equipment Requirements

| Process | Capacity | Utilities |
|---|---|---|
| Conveyor ultrasonic cleaner | — | 115 V, single phase |
| *Active assembly* | | |
| TC die bonder | 1000 to 4000 dice/hr | 115 V, single phase, vacuum |
| Ultrasonic die bonder | -- | 115 V, single phase, nitrogen, vacuum |
| Ultrasonic aluminum wire bonder | — | 115 V, single phase |
| Ultrasonic gold wire bonder | 2000 to 3000 wires/hr | 115 V, single phase |
| Thermosonic wire bonder | 1500 to 2000 wires/hr | 115 V, single phase, vacuum |
| Pulse heated TC wire bonder | — | 115 V, single phase, hydrogen, vacuum |
| Automatic thermosonic wire bonder | 7200 wires/hr | 115 V, single phase, |
| Work benches, vertical laminar air flow | — | 115 V, single phase, 230 V, 3 phase |
| Epoxy bonder | — | 110 V, single phase, vacuum |
| Epoxy bonder | — | 115 V, single phase |
| *Encapsulation* | | |
| Hermetic sealing | — | 115 V, single phase |
| Injection molding | — | 115 V, single phase |
| Conformal coating | 600 1 x 1 in substrates/hr | 115 V, single phase |
| *Test and failure analysis* | | |
| Probe stations (2) | — | — |

initially be directed into this area for evaluation. This initial check will ensure that all incoming components and materials conform to specifications. The area will include equipment necessary for close detailed visual inspection, probing, and electrical testing of both active and passive chip components. In addition, some thick film processing equipment such as a printer, furnace, and viscometer will be used to make sample tests of the properties of all batches of thick film materials.

(2) *Storage.* This area will be entirely under the control of the quality assurance staff from area 1 above. The components and materials that will be required for various projects will be stored here under limited access control. This will ensure use of qualified materials on all programs and will prevent unauthorized use of the qualified materials.

(3) *Layout and Artwork.* This section will control the preparation of and a file system for artwork

involved in screen manufacture. In addition, this group will be responsible for developing and overseeing the engineering process and flow control. The processes, steps, materials, and procedures will also be documented at this point.

The layouts made in this section may utilize either a drafting table or a polar coordinatograph, both of which are available. Special or complex artwork will be prepared on the interactive computer-aided design (CAD) artwork generator used primarily by the Printed Wiring Facility. With this equipment, rubylith masters will be prepared for photographic reduction. The reduction itself will be handled in the printed-wiring board fabrication facility, and from there the screens will be prepared at qualified contractor facilities. The reason for having this last operation performed outside the facility is that experience has shown that competent contractors are able to make good screens, cheaply and just as quickly as can be made in house. This is not true for other process steps.

(4) *Print and Fire:* It is in this area that the bulk of thick film fabrication takes place. The printed-and-fired substrates made here provide the basis for hybrid assembly. This section also fabricates components such as printed conductors, resistors, capacitors, crossovers, etc. The equipment consists of automated screen printers, conveyor dryers, and conveyor furnaces. This equipment has been sized for a production capacity that experience shows is necessary in order to closely simulate full production capabilities and capacities, and to disclose potential problems that may arise in performing these functions.

(5) *Resistor Trimming:* Resistors are automatically trimmed to value at this point. The laser system that will be available for this function (and its associated computer control) will be able to trim resistors to close tolerances at production rates either in a passive situation (trim made to a specified resistance) or in an active mode in an operating circuit with trim made to a specified circuit parameter such as frequency or voltage.

(6) *Passive Assembly:* The passive assembly area will allow automated placing of components, solder reflow, and subsequent cleaning operations. The automated parts placer is controlled by a microprocessor which can use the same program generated for the location of wire bonds for the automated wire-bonding operation in the active assembly area described next.

(7) *Active Assembly:* The operations performed in this section are extremely important to the hybrid process. Two major steps are performed—placing active chip devices onto the substrate and "wiring" them into the circuit. This area will require an automatic, thermosonic wire bonder with a large enough capacity to simulate production-type processes and techniques. In addition, several manual bonders of various types will provide an accurate simulation of many, if not all, the types of bonding available to the industry generally, now and in the foreseeable future.

This section provides die bonding of several types: i.e., epoxy bonding, thermocompression die bonding, and ultrasonic die bonding. In addition, the types of wire bonding available are ultrasonic wire bonding of both gold and aluminum wires; thermosonic wire bonding; pulse-heated, thermocompression wire bonding; and fully automated, computer-controlled, thermosonic wire bonding. These capabilities will allow the facility to closely simulate any type of process used in a production situation

(8) *Encapsulation:* Because of the variety of packaging techniques possible in fuzing applications, this facility provides production capabilities for three major types of encapsulation: hermetic sealing, conformal coating, and injection molding.

(9) *Test and Failure Analysis:* This area will provide us with a facility to test finished products and perform failure analysis. The "heart" of this section will be the Hewlett-Packard 9500D Automatic Test System, which is already an HDL operating facility.

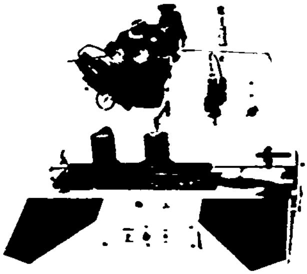

Figure VII-4. Epoxy die bonder.

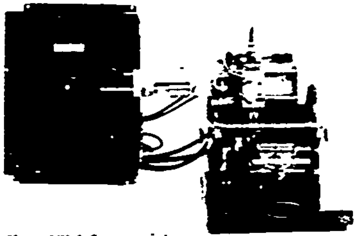

Figure VII-6. Screen printer.

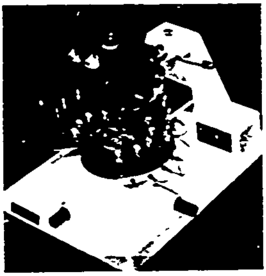

Figure VII-5. Probe station.

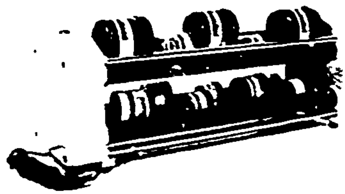

Figure VII-7. Jar roller.

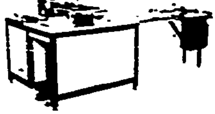

Figure VII-8. Automatic screen printer.

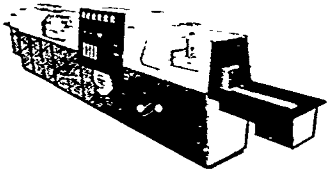

Figure VII-9. Conveyor furnace.

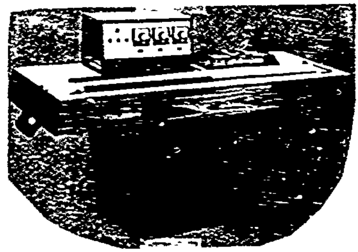

Figure VII-12. Automatic reflow soldering system.

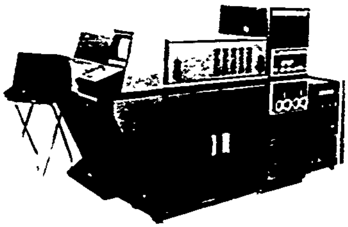

Figure VII-10 Automatic laser trimmer.

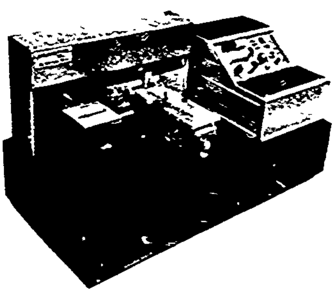

Figure VII-11. Robot parts placer.

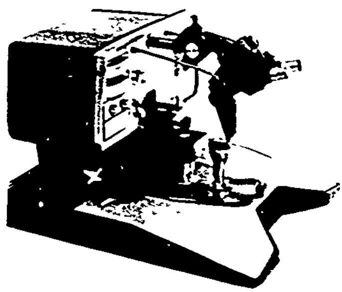

Figure VII-13. TC die bonder.

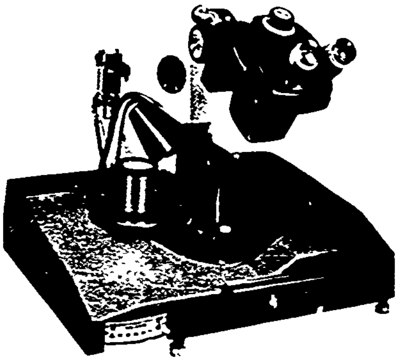

Figure VII-14 Ultrasonic die bonder.

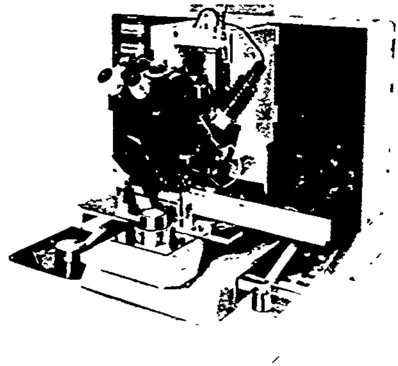

Figure VII-16. Beam lead bonder.

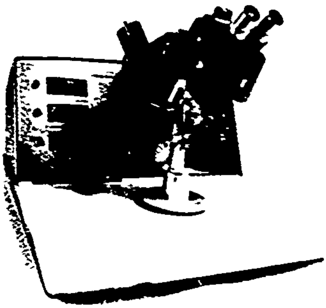

Figure VII-15. Pulse heated TC wire bonder.

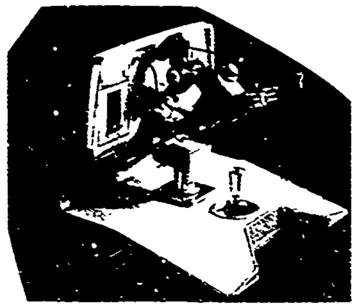

Figure VII-17. TC wire bonder.

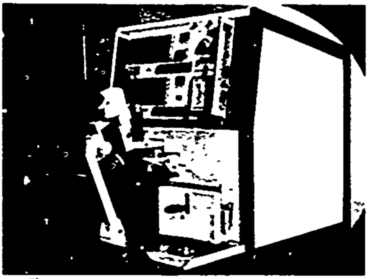

Figure VII-18. Automatic TC wire border.

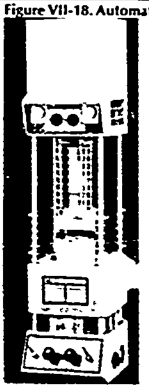

Figure VII-19. Injection molding machine.

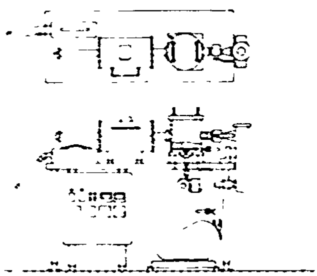

Figure VII-20. Conformal coater.

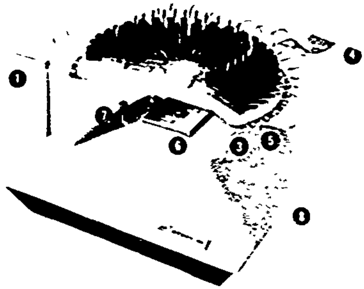

Figure VII-21. Probe station.

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# Chapter VIII. Prototype Validation Facilities for Inspection and Testing Systems

by Horace E Brown, Jr

## VIII-1. Background

Fuzes and their component parts developed by HDL fall into two general categories, depending on the weapons for which they are designed Missile fuzes are usually very complex, expensive devices, requiring almost 100 percent reliability, and are produced in relatively low volumes Conventional hand assembly for this type of production facility would probably be mandatory On the other hand, rocket mortar, and artillery fuzes are usually less sophisticated electronically are used in far greater numbers operationally, and must be produced in large quantities to meet military logistic needs These latter fuzes are candidates for modern automatic manufacturing techniques of fabrication, assembly, and testing

When high production rates exist, a reduction in unit cost of only a few cents per unit can return savings of hundreds of thousands of dollars This dollar saving if it is to be of true value to the government, must be achieved without downgrading a unit s electrical integrity or the military characteristics of the fuze Reliability must remain high, storage life must not be compromised and operational features must not be degraded Assurance that these conditions are met can be enhanced by comprehensive measurement inspection, and testing procedures during the manufacture of the fuzes

Numerous measurement and inspection techniques already exist and are being used in automatic fabrication and assembly lines for commercial mechanical and electrical items. Many of these methods are directly applicable to fuze manufacture, and the user can incorporate them into an automatic line with a high degree of confidence Other aspects of fuze testing, however, particularly special conditions applying to radiating-type proximity fuzes, have no direct counterpart in high production items on the commercial market For adequate and reliable acceptance testing methods and procedures to be available at the time production is started, the hardware and documentation must be prepared and verified during the fuze development phase

## VIII-2. Recommendations

A facility is required that will allow the development of comprehensive test and measurement methods and test equipment concurrently with the fuze design This would assure that, at the time a contract is let for production of fuzes in large quantities, an accurate testing system would exist to test and evaluate units rapidly and inexpensively. The required system should incorporate at least the following general capabilities

(a) Provide the necessary mechanized assemblies that will allow the test system to operate dynamically in a completely automated mode Mechanical handling equipment shall be provided to pick up the fuze assembly from handling trays load the fuze into a proper rf load box when needed, and automatically stimulate and measure fuze parameters upon request

(b) Determine whether measured parameters are within predetermined limits

(c) Mark all fuzes which do not meet the above criteria with a unique symbol, which will show the specific fuze parameter that was failed The panel of the test station should also be marked. to alert the operator of the failure

(d) Provide equipment to remove the fuze and automatically place it in appropriate bins (accept, reject, and re-work), after tests are complete

(e) Provide a real-time data-acquisition and processing system for fuze testing during acceptance

(f) Keep a running frequency distribution for each fuze parameter measured so that means, standard deviations, and failure rates can be determined

(g) Provide a printed record of analyzed data

(h) Provide data storage for further rigorous statistical analysis

## VIII-3. Equipment Required

The production equipment—whether rotary table nonsynchronous transport system, or other type—will be selected by the fuze design requirements. Test stations must then be implemented as required, and the selected system of transducers and fixturing must be designed and installed on the production equipment

It is expected that a minicomputer would control the complete operation of the test system and would also be able to acquire data on command from the satellite stations that compose a complete test facility. Once acquired, the data would be statistically processed to pinpoint trends of fuze parameters. The minicomputer, on command, would either assume total control of the microprocessor-controlled satellites or would acquire data from the satellite stations. Each satellite station would have enough circuitry incorporated into its hardware to sequence its own tests, issue Go/No-Go decisions, and temporarily store data from one of two measurement cycles

In the automatic mode it is envisioned that the central processing unit (CPU) would totally control the operation, retrieve the temporarily held data on demand, conduct various statistical exercises (also on demand) and issue a printout. In the local mode, each satellite station would operate independently. Because this mode of operation excludes computer operation, no data would be recorded. Operation in this mode is basically intended to allow the line to perform if a computer breakdown were to occur

The following are typical satellite stations for artillery proximity fuze testing and the tests performed by each station

(a) Oscillator/amplifier assembly station fire delay, current detector, frequency (oscillator), rf sensitivity, fire pulse energy, rf power, integration time, noise rejection, low height of burst (HOB), mid HOB, high HOB

(b) Amplifier assembly station current, arming time delay (firing delay), select R9 and 3 HOB tests performed, battery noise (noise rejection), integration time, fire pulse energy

(c) Oscillator test station rf frequency, detector voltage, rf power, current, rf sensitivity

Two of these stations are normally required for measurements before and after the assembly has been encapsulated in a potting material

For performance of the oscillator/amplifier assembly testing, the following example of options that could be proved in at the PVF is presented

## VIII-4. Examples of Tester Design Approaches

### *VIII-4.1 In-Line Production*

The present government design of the oscillator/amplifier tester is not conducive to in-line testing, but was developed for DECASD buy-off tests. It is judged that 100-percent testing of the oscillator/amplifier (potted) is required in production. Therefore, the following approaches are offered for adapting this test to in-line production

*Automatic Feed of Assembly D-1* —In this mode, two chambers are used on a modular console (as the tester is presently being designed). Oscillator/amplifier assemblies are automatically fed and placed into the sockets of the chambers. The chamber doors are automatically opened and closed, and the tester is automatically operated. Electronics remain multimatrixed. Operation would be as follows. Oscillator/amplifier assemblies would be delivered to the testing station on cartridges or magazines. Each station would be

equipped with an automatic feed and transfer device which would take assemblies from the cartridge and insert them into the sockets of the chamber doors The doors would automatically open and close While chamber A is performing tests, chamber B would be unloaded and reloaded automatically Rejected assemblies would be maintained Accepted assemblies would be returned to a storage cartridge or magazine This mode is shown in figure VIII-1

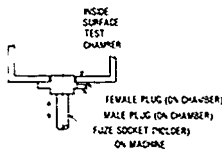



**Figure VIII-1. Test chamber, automatic feed, and plug-in.**

The tester would require the following redesigns

(a) Automatic operation of doors, preferably, doors should open down

(b) Automatic start of tester

(c) Use of reject signal to operate control of feed mechanism for rejection of component

(d) Redesign of sockets to permit automatic insertion A special, temporary type of socket may have to be used, where the oscillator/amplifier assembly is first inserted into the special socket before it is fed to the chamber

This system has the following characteristics

(a) Low rates (approximately 120 units per hour at 100-percent efficiency, therefore, at least six, and preferably seven or eight systems are required for a production line, but not for the PVF)

(b) Operation that is relatively expensive and cumbersome

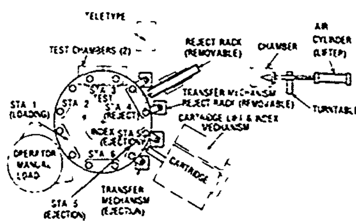
(c) One operator (minimum) required per two systems

(d) Operator decision eliminated in placing rejects into proper rack

(e) Protection of production flow due to tester down time since several testers are employed

(f) Extensive debugging and troubleshooting to perfect the automatic feed can be expected initially due to the nature of the product.

*Rotary Turntable* —In this mode, two chambers are used, with electronics again multiplexed Oscillator/amplifier assemblies are manually loaded and automatically unloaded from the table A memory system is provided for automatic rejection of reject assemblies Reject assemblies are stacked, in order until a given number, 15 for example, have accumulated The turntable would then cease to operate until the rejected assemblies were manually unloaded The tags would be typed in proper sequence, and would be manually attached to the rejected assemblies when they were removed This mode is shown in figure VIII-2 Operation would be as follows




1 SIX STATION DUAL INDEXED ROTARY TURNTABLE (TWO NESTS PER STATION)

2 ALTERNATE MODE TWO STATIONS (AS STA 2 & 3), WITH TOTAL 4 TESTING POINTS SEVERAL PARAMETERS TESTED AT STA 2 WHILE REMAINING TESTS PERFORMED AT STA 3

**Figure VIII-2. Rotary turntable, oscillator/amplifier tester.**

Two E-heads are tested simultaneously, requiring approximately 40 s During this period, the operator places the two assemblies to be tested into sockets on the turntable At the completion of the test cycle, the turntable indexes (two stations)—provided, of course, that two additional assemblies have been inserted by the operator The tester assemblies are now at the reject station, where any units failing to pass the tests will be automatically stacked in the reject rack At the next index, the assemblies are ejected into a cartridge or magazine

This system offers the following features

(a) Relatively inexpensive and simple operation

(b) Low rates (approximately 160 units per hour, therefore at least four systems are required in production)

(c) From (b) above, at least four operators, plus one support person, would be required

(d) Elimination of operator decision in placing rejects into proper rack

(e) Protection of production flow due to tester down time, since several testers are employed

*Rotary Turntable—Horizontal Mode*—This approach is a variation of the rotary turntable approach, but here the sockets travel horizontally This mode which has all the advantages listed above, but permits the present modular stacked design of the tester to remain, is shown in figure VIII-3.

*Linear Indexer*—In this mode several chambers are used with electronics multiplexed Here, one or more operators load oscillator/amplifier assemblies into sockets on the linear machine while other units are being tested At the end of the test cycle, the tested units index to a reject station where units that have failed the tests are automatically unloaded (in proper sequence) into special reject racks At the next index cycle the assemblies are presented to the automatic unloading station where they are stacked into cartridges or magazines This mode is shown in figure VIII-4

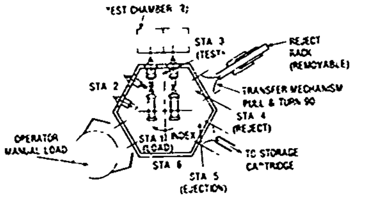



**Figure VIII-3. Rotary turntable, horizontal mode, oscillator/amplifier tester.**

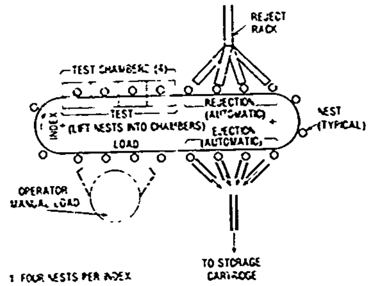



**Figure VIII-4 Linear indexer, oscillator/amplifier tester.**

This system offers the following benefits and limitations

(a) Simple operation, somewhat more expensive (per unit) than the automatic feed approach

(b) High rates, depending on number of chambers and amount of multiplexing Assuming four chambers with a 40-s test cycle, an approximate production rate of 320 assemblies/hr is expected, with one operator Two such lines would be required with eight chambers, production rate would be doubled, but two operators would be required

(c) From (b) above, requirement of at least two operators, plus one support person

(d) Elimination of operator decision in placing rejects into proper rack

(e) Protection of production flow with two systems, in event of down time

(f) Modular design possible for testers, permitting quick plug-in of tester or chamber in the event of a problem In addition any given chamber may be bypassed by blocking off its related loading station

(g) Versatility permitted in testing By changing index cycle, assemblies may be tested in two (or more) sequential chambers or stations, permitting certain tests to be run concurrently at different stations This may increase rate and reduce complexity of multiplexing

*Belt (Linear)* —This approach is similar to the linear indexer approach above, differing only in configuration This system offers all the various advantages and disadvantages listed above, with the exception that it is less expensive and more compact The linear belt system is shown in figure VIII-5

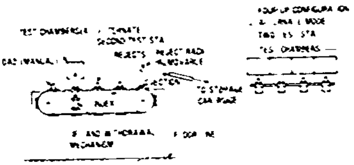



**Figure VIII-5. Linear belt, oscillator/amplifier tester.**

*Belt (Linear-Horizontal Mode)* --This system is also similar to the linear indexer approach with the same basic operation

Other methods examined included the use of temporary connectors, multiple connector boards, etc , but were evaluated as having no primary advantage

Of the several methods investigated, the last two, belt (linear) and belt (linear-horizontal) are recommended as best meeting production requirements with a minimum of capital equipment costs and a minimum number of operating personnel

In addition, it is conceivable that operation could be completely automatic—i e , automatic feed of assemblies to the drive belt, but this would require an attendant, thus reducing the total payoff of such a device In addition due to the nature of the product, this type of element could be expected to be cumbersome and troublesome, although, with some future product design of the fuze a reliable, efficient feeder could later be installed

From a total systems approach, manual feeding is advisable—at this stage—because a relatively minor manual operation precedes this test This operation is the breaking off of the fill tube (from potting), and could easily be combined with feeding to the tester, thus combining the operations

### VIII-4.2 Oscillator Tester

The oscillator tester performs the functional tests on the antenna/oscillator assembly The tester provides the assembly under test with the specified operating power and environment The functional tests consist of measurement of

(1) dc current,

(2) detector output voltage

(3) rf power, and

(4) rf frequency and sensitivity

*Carrier Frequency Test (present method)* -- First, dc power is applied with a 1-min time delay

The rf energy from the fuze antenna is then coupled to the mixer via the probe. The motor driven swept oscillator (LO) is stopped when an output is detected at the 60-MHz amplifier/detector The output of the LO is precalibrated and monitored on a frequency counter (see fig VIII-6)

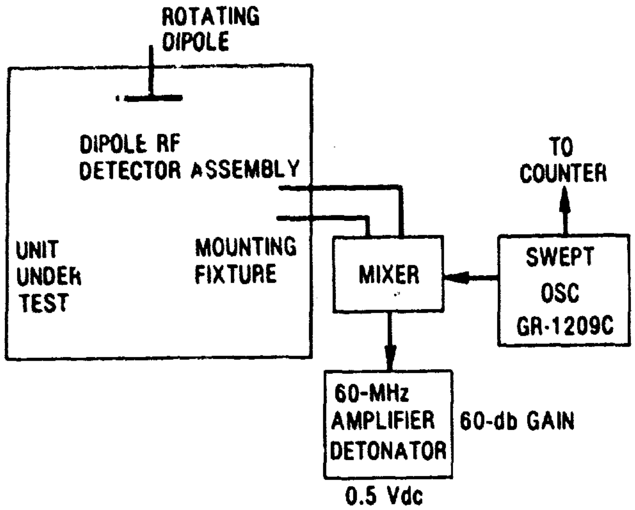



**Figure VIII-6. Carrier frequency test diagram (present method).**

*Carrier Frequency Test (proposed method).*—No change to the existing test chamber is required (see fig. VIII-7).

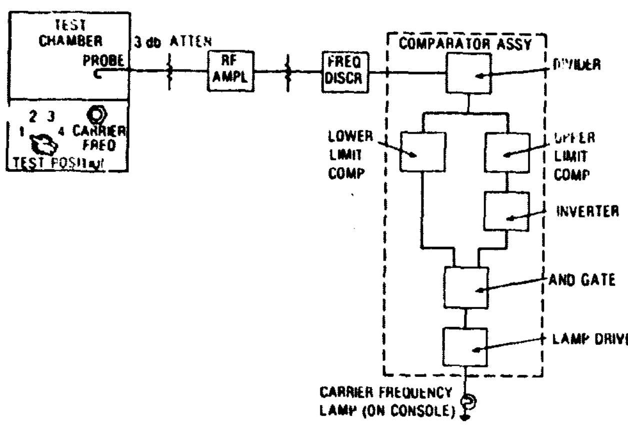



**Figure VIII-7. Carrier frequency test diagram (proposed method).**

The rf carrier is coupled to an rf amplifier by the existing coupling probe on the right-hand wall of the chamber. The amplified signal is directed to a frequency discriminator with an output voltage proportional to frequency. The output voltage of the discriminator drives an adjustable threshold comparator circuit. The comparator circuit determines whether the voltage from the discriminator lies between $V_{min}$ and $V_{max}$. If the voltage is between $V_{min}$ and $V_{max}$ (fig. VIII-8) the AND gate is output, and a lamp driver is turned on, indicating that the oscillator is within specification.

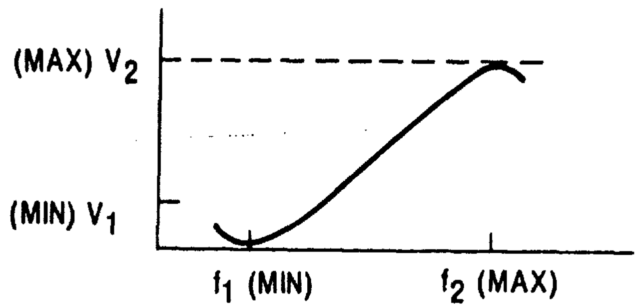



**Figure VIII-8. Discriminator output.**

*Measurement of Anterior/Oscillator Operating Current.*—The measurement of anterior/oscillator current can be done using the present technique, with the possible exception of the addition of a Go/No-Go lamp on the test console, indicating that current is within specification limits.

*Measurement of Radiated Power.*—The radiated rf power is received by the dipole and rf detector assembly on the rear wall of the chamber. This measurement is presently made by reading the calibrated detector output on a digital voltmeter. A Go/No-Go test can be implemented which lights a lamp on the console when the detector output reaches a level equivalent to the required minimum of 150-mW rf output power.

*Sensitivity Adjustment.*—The sensitivity adjustment is made by simulating a doppler signal and adjusting the rf coupling to the antenna and the oscillator for optimum fuze detector output. The doppler signal is simulated by spinning a dipole antenna at the top of the chamber at 3600 rpm. This is then equivalent to a constant doppler reflected signal of 120 Hz seen at the antenna terminal.

The oscillator sensitivity is a function of the transistor parameters: mainly, transistor $f_T$, other circuit component parameters, dielectric constant and thickness tolerances of the copper-clad board material, and the effects of the potting material.

Oscillator sensitivity adjustment is very difficult to automate because it involves the manual operation of connecting the capacitor parts. One method of making this adjustment is to bridge the gaps between the pads with conductive paint; however, the resistivity of conductive paint normally changes with drying time. Another method is to connect the pads before testing and remove the connections during test. The third alternative is to empirically determine which pad connection will allow a majority of the assemblies to meet the specification and make this adjustment on all fuzes prior to test. The tester can then be automated for a Go/No-Go sensitivity measurement. The assemblies that pass can be diverted to manual test positions for adjustment. One automatic and one manual test position would be required. Supporting argument for this last approach is as follows.

Figures VIII-3 and -9 show the correlation between oscillator sensitivity change after potting and transistor $f_T$. It shows that if the mean sensitivity is adjusted 13 percent high before potting (mean value of 113 mV), and the transistor $f_T$ varies from 700 to 1300 MHz in any lot, then the sensitivity will vary approximately $\pm 10$ percent ($\pm 10$ mV). The specification limits for sensitivity are approximately $\pm$ 40 percent.

This allows approximately $\pm 30$-percent change in sensitivity with transistor $f_T$ and other circuit parameters. If the change in sensitivity with $f_T$ and other circuit parameters were empirically determined, this would allow presetting the sensitivity adjustment before assembly with maximized production yield.

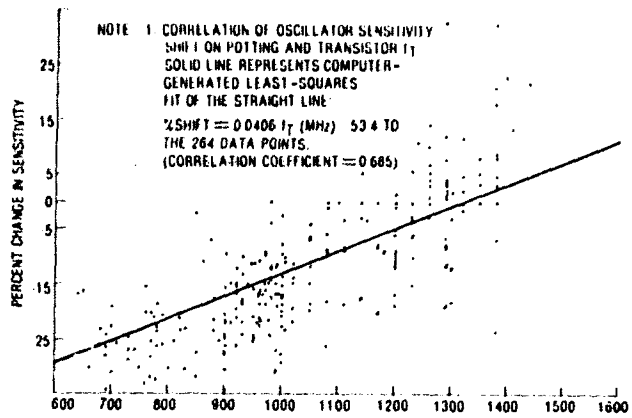



**Figure VIII-9. Correlation between sensitivity change after potting and transistor $f_T$ data obtained from HDL.**

## VIII-5. Conclusions

A facility should be assembled to prove that a high-volume 100-percent testing system will electrically be able to stimulate the fuze or module under test and retrieve the results of the reaction so that meaningful decisions on the unit's performance can be readily made.

## Chapter IX. Centralized Environmental Validation Test Facility for HDL

by Abraham Frydman

### IX-1. Introduction

#### *IX-1.1 Summary and Update*

Fuze design at HDL has included "environmental" testing during the development stages, even though it may not have been thought of in those particular terms. Such tests were usually selected by the designer and ranged from simple, rigged bench tests to setback tests made with gas guns and centrifuges, and spin tests made with appropriate spinners (more recently with the HDL artillery simulators). Advancements in the gas gun and artillery simulator test facilities/procedures demonstrated their credibility for validating structural and operational design reliability. Good correlation between laboratory tests and subsequent field tests created a situation in which the fuze designer eventually placed greater emphasis on preliminary "environmental" testing. Of course, the preproduction-developed fuze was still run through the prescribed MIL-STD tests, and test plans were formulated for various types of "buys" and for production lot acceptance criteria. To a large extent, the tests, plans, and specifications were selected by the program manager after consultations with the environmental engineer.

In the last several years, the HDL environmental test laboratory equipment and capabilities have been modernized. In addition to the conventional altitude-temperature-humidity and other MIL-STD environments, HDL has updated its facilities by inclusion of impact-type testers and various types of analog and digital computer-operated shaker systems. There has also been increased emphasis on innovative and time-saving test methods such as transient waveform control (TWC), shock spectrum synthesis (SSS), random vibration testing, and modal test and analysis.

The proposed PVF provides the opportunity to restructure and reorient the present operations to optimize existing goals. To start with, the environmental engineer will be able to provide much greater support to the fuze designer in the selection and timing of proper environmental tests and to do so throughout the development cycle. In addition, the environmental engineer will, through familiarity with the product design, be able to select and validate reduced MIL-STD test requirements and, in some instances, even introduce validated nonstandard tests that will provide considerable cost savings through markedly reduced test times.

In the following sections of this chapter it will be seen that considerable use is expected of computerized systems. The use of computers is a feature that even in a limited sense would be a powerful fuze design aid. Its support role for environmental testing will be readily apparent from the following descriptive material. It should be equally appreciated that coupling environmental testing throughout the entire fuze development cycle and into the preproduction runs will result in hardware that provides maximum structural integrity, optimum environmental durability, and operational reliability validated to user-prescribed battlefield conditions.

#### *IX-1.2 General Description, Purpose, and Concept*

The foregoing concept is concerned with the establishment of a Centralized Environmental Validation Test Laboratory (CEVTL) to provide test support for the simulated fuze mass-production operations performed at the fuze PVF. The proposed CEVTL will use dedicated computer equipment and conventionally controlled environmental test equipment for the dual purposes of performing accelerated and conventional design validation testing. Emphasis will be placed on the accelerated test method in order to reduce turnaround time by an estimated factor of as much as one-half. Also, it is planned to upgrade the level of confidence in the test results because of the ability to test larger lot sizes per unit time. A central processing unit (CPU) will rapidly develop test data bases to be used to validate or reject prototype fuzes/subassemblies or fuzes under development, based on proof of design, overdesign limits, design to cost, or

similar types of acceptance criteria. To reduce production costs for a particular fuze design, limited numbers of prototype fuzes will be manufactured using production-line techniques as opposed to the, conventional method, which resorts to custom-made tool-room techniques. These simulated production runs early in the development stage will identify and fix potential production-line problems, demonstrate the mass-producibility of a particular design, and provide quantitative unit-cost estimates before the Technical Data Package (TDP) is released to industry. To ensure, however, that product reliability has not been compromised by the selected production-line techniques, prototype fuzes/subassemblies would have to be tested to simulated or accelerated service life. Thus, test data conveniently collected and stored within the CPU, when analyzed by a preprogrammed mathematical model, can be used to rapidly ascertain the adequacy/integrity of the mass-produced fuze. If necessary, the mathematical model can be further extended to determine the probability that a particular fuze can survive the rigorous field-acceptance tests which are used to determine whether the fuze is ultimately approved for full-scale production. The mathematical model can also establish confidence limits for the fuze.

Practical developments in state-of-the-art dynamic testing, manifested by computer-based techniques, make it possible to rapidly expose prototype fuzes/subassemblies to simulated/equivalent field damage. For example, field damage resulting from transportation vibrations can be measured in a matter of minutes or hours rather than days (the usual time for acceptance testing). This time saving is achieved by substituting intense random vibrations for the standard harmonic excitations. This and similar test techniques (such as the Shock-Transient Waveform Control Testing and Airgun Testing) skillfully applied can minimize pre-production costs by scaling down the magnitude of field testing on prototype fuzes. Furthermore, readiness is improved because of a substantial reduction in assessment time as well as ever-increasing computer-based simulation testing.

The concept of equivalent testing, although demonstrated in practice,[1,2] often requires extensive empirical and analytical efforts for demonstration of the correlation between laboratory and field tests. In some cases, test techniques developed for one product must be modified in order to apply to others. In the past, such an effort was prohibited because of the high cost of prototype fuzes. However, the availability of a fuzing PVF (furnishing prototype fuzes and components at economical unit cost and in sufficient quantities relatively early in the production stage) is expected to make such a correlation effort possible. The PVF should also provide for reasonable lead time for any necessary redesign modifications before the TDP is released to industry. Such modifications may also include product redesign to reduce unit cost if the margin of safety is determined to be unreasonably high.

The accelerated testing proposed here could be performed reliably on prototype fuzes at various stages of production without interfering with production-line operations. However, it is recognized that terminal phase testing of the end-item fuze(s) is the most cost effective. Therefore, the CEVTL will be designed toward performing environmental validation testing as specified for the assembled component/system, such as for first-article acceptance samples of thermally conditioned electronic subassemblies (E-heads), impact switches, and fully assembled fuzes.

The proposed CEVTL will resort to the innovative use of a CPU and dedicated digital minicomputers to meet three primary objectives:

(a) automatic test control/monitoring of advanced simulation test equipment,

(b) data acquisition and documentation of the raw test results, and

[1] *W. C. Facker, Equivalent Techniques for Vibration Testing, Naval Research Laboratories, SBM-9 (1972).*

[2] *Cyril M. Harris and Charles E. Creed, Shock and Vibration Handbook, 2nd edition, McGraw-Hill, New York (1961).*

(c) overall evaluation of the raw test results in accordance with the predetermined criteria to aid in decision-making for mass producibility and cost effectiveness of the fuze designs under consideration.

To meet objective (a), the CPU will be used partially as a library source for storage of test-simulation codes developed especially for the accelerated test method. As an example, consider the use of the accelerated test method to simulate rough handling environments in the field that are characterized by complex shock signatures (damped shock transients with variable amplitude and frequency components). Such signatures—hereto impractical to generate conventionally—can now be synthesized on electrodynamic vibration generators within minutes using computer-based shock TWC test techniques. To simulate the same environments conventionally, one would have to resort to lengthy and costly field and laboratory testing, as no practical laboratory test methods exist now.

Use of the CPU or dedicated mini-digital computers in test applications to meet objectives (b) and (c) is clear. The CPU referred to here is a PDP 11/45 computer and peripherals or other remotely connected ADP equipment having equivalent computational capabilities.

In summary, proximity environmental validation testing capabilities can be reliably incorporated in the fuzing PVF operations. Using conventional and special test equipment operating under a local controller, prototype fuzes and subassemblies would be tested at the final level of assembly (unless otherwise specified) to assess the mass producibility and cost effectiveness of a particular design. Raw test data for a limited lot size will be entered into a centralized data bank and analyzed to determine proof of design, design margin, and possible modifications to reduce unit cost.

Tables IX-1 and -2 present a summary of the floor plan, test equipment, and utilities required to support the proposed CEVTL (communication lines to CPU not shown). The same test equipment is used whether or not accelerated or conventional testing is performed.

The proposed concept for environmental validation testing is not a substitute for the formal product acceptance tests. Rather, it is primarily intended to provide a means for quick assessment of a particular design, indicating whether it has been compromised by mass-production techniques, without the need for costly and extensive field tests for every production run. Final acceptance of the product still depends on compliance with the formal field tests.

## IX-2. Environmental Validation Tests

The following types of tests are proposed in support of the environmental validation process.

(a) Mechanical vibrations—harmonic, random, and mixed mode—simulating various transportation environments for munitions

(b) Standard mechanical shock—simple, composite, one-sided—simulating rough handling of munitions

(c) TWC testing—nonstandard mechanical shock—digital control techniques used to synthesize user's specified complex shock signatures

(d) Shock spectrum—primary, residual, and maxi-max—simulating rough handling and other high-shock environments. This form of testing is not specified in military standards, but is computed from field data for a specific fuze environment

(e) Least favorable test method response—composite worst-case shock envelope for a multitude of field conditions used primarily to accelerate test time

(f) Air gun launch shock—simulated gun ballistics, including spin and environmental conditioning effects

(g) Temperature/humidity/thermal shock—conditioned thermal cycling to simulate field or depot storage environments and/or dor-

mant status before execution of dynamic testing

(h) Pressure/altitude (vacuum)—simulating airborne transport of munitions, effectiveness of moisture-resistant seals, etc

(i) Standard rough-handling shock—5-ft and simulated 40-ft drop tests, quantified jolt, jumble, etc

(j) Other—such as salt spray—performed to validate corrosive resistance of materials to corrosive storage environments

### *IX-2.1 Testing Procedure, Documentation, and Data Analysis*

A limited quantity of prototype fuzes/ subassemblies will be subjected to the type of tests specified in section 2. For optimization of test operations, the smallest (but statistically meaningful) lot size will be tested at selected test stations. As many test operations as technically or sequentially possible will be run concurrently, such as multi-chamber or multi-shaker control. Such automatic operations will require computational/ processing* of test data, retrieval, storage, and CRT display capabilities accessible from the testing area. Because of the automated test operations proposed, between two and three mid-level technicians will be required to perform environmental validation testing.

### *IX-2.2 Environmental Accelerated Test Design*

In general, no accepted specifications exist for accelerated environmental testing of electronic fuzes. Guidelines and procedures are available for accelerated aging environments such as depot storage and 20-year fatigue life for shipboard equipment. In most cases, however, accelerated testing for specific fuzes will have to be developed almost on a custom basis and, to be effective, this will have to be done within the development cycle of the product. The design of such tests will require that original work be done in areas such as damage/wear mechanisms, equivalent deposition of mechanical/thermal energy, exaggeration factor theory, and statistical correlation techniques. Efforts of this type will have to be supported concurrently with actual prototype development to achieve ultimate potential of the PVF operations. The particular applicability and weighted contributions of each of the operation/survivability prototype parameters will have to be evaluated with respect to the specific product and to the particular type of field environment considered most demanding. Validation tests on production hardware will have to be performed initially (in those cases where existing or relevant data can be obtained) to demonstrate damage equivalency of any proposed/developed accelerated test procedures. Eventually, some accelerated tests will achieve general recognition and reach the acceptance level of the current MIL-STD tests.

### *IX-2.3 Standard and Nonstandard Tests*

The CEVTL validation process will include both standard and nonstandard tests. Standard tests are usually specified in considerable detail in Military Standards (e.g., MIL-STD-810C, MIL-STD-331) or other official documents such as procurement specification control drawings (SCD's) and ASTM/ANSI codes. As a result, each test is well-defined in its requirements, applications, and purposes. Nonstandard tests, on the other hand, may also be quite detailed and equally valid for their intended purpose; nevertheless, they are characterized by user-defined specifications. Although these tests may eventually be described on SCD's delineating specific environments for a given fuze, they are, in most instances, specific to a particular program and do not have general applicability.

Quite often, such environments (tests) are requested by the user who is intimately familiar with the field environment, or they are introduced by the engineer/designer following successful usage during development. Developed nonstandard test plans must permit flexibility in test operations. It may be expedient (though in some cases absolutely necessary) to allow contract test engineers to adapt

**To the extent that no dedicated computer is available, it is proposed that this task be supported by an HDL PDP 11/45 processor or equivalent ADP equipment.*

or modify test facility equipment and procedures. However, experience and a thorough knowledge of the product, its environment, and the test itself are required before such changes can be adequately evaluated. In any event, test plan modifications should be discussed with the environment engineer and receive user approval before the start of contract testing.

Several nonstandard test techniques are now more widely used for dynamic, accelerated testing. They include the following.

(a) TWC using digitally controlled vibration generators (used to simulate user-prescribed complex acceleration time histories). This test method can be used successfully to simulate a variety of complex shock events that are readily synthesized electronically. However, due to current existing equipment limitations, this method cannot be applied for shock levels exceeding 1000 g.

(b) Shock spectrum testing (simulating the damage-dependent frequency content of a complex shock event). This method can be used reliably to generate frequency components in excess of 50,000 g.

(c) Interior ballistic techniques (simulating gun launch shock/spin effects) using various types of air/gas guns and flight boosters.

(d) Equivalent vibration damage techniques (especially effective in reducing test time—typically from hours to minutes).

Accelerated testing usually starts with the one considered environmentally most damage-inducing or environmentally most failure-prone, followed by tests of decreasing environmental severity. This may be justified on the grounds that if the item survives the most severe test it will probably satisfy the remaining tests. More practically, it saves test time by pinpointing rather quickly any defects that require reconsideration or redesign. The CEVTL computer system will include assessment capability of design/overdesign margins in terms of confidence levels. It is expected that accelerated testing will become more prevalent because of ongoing research and development in this technology and the need to reduce project development/test costs.

The advantages and disadvantages entailed in the two test methods are given as follows.

| Method | Advantage | Disadvantage |
|---|---|---|
| Accelerated test | Potential reduction of test time by 50 percent and more | Extensive development effort to establish equivalency. |
| Conventional test | Procedures available and valid | Lengthy (as long as 1-1/4 months) |

Regardless of the test method selected, the following parameters could be assessed based on the proposed concept for environmental validation testing.

- Design/overdesign limits (system level)
- Potential mass-reproducibility problems affecting design integrity (component level)
- Cost effectiveness (versus overdesign margins)

### *IX-2.4 Fixture Design and Fabrication*

The concept of environmental testing proposed here will require design and fabrication of semi-universal test fixtures to permit quick adaptability and interchangeability of test setups. One advantage of universal fixtures is the cost saving that is realized when they are already available. However, the design and fabrication of an adequate stock and range of universal fixtures requires a substantial initial supporting engineering effort.

## IX-3. CEVTL Personnel

Test operations in the CEVTL will be conducted by three technicians under the guidance of two professional staff members. Each technician will perform tests assigned to his station, testing the required number of specimens commensurate with a given task. To minimize cost, tests will be run concurrently whenever possible. To further optimize test operations, test personnel will be trained in all operations applicable to their grade level. The use of automated equipment for operations and documentation will offset the limited staff size. Staffing does not require additional personnel.

**Table IX-1. Test Equipment and Utilities in Room N-2 of Proposed CEVTL**

| Item | Measurements | | | | Electrical Characteristics | | |
|---|---|---|---|---|---|---|---|
| | Depth (in.) | Width (in.) | Height (in.) | Weight (lb) | Volts | Phase | Amperes |
| (1) Rough handling,3 | 48 | 48 | 36 | 300 | 115 | 1 | 20 |
| (2) Centrifuge | 60 | 60 | — | 700 | 330 | 2 | 20 |
| (3) Impact/shock tester | 32 | 76 | 180 | 5000 | 220 | 2 | 10 |
| (4) Teletypewriter with CRT display | 24 | 36 | 40 | 80 | 225 | 1 | 5 |
| | CRT d | | | | | | |
| (5) 5-ft Drop tester | 36 | 46 | — | 500 | 115 | 1 | 5 |
| (6) 40-ft Drop simulator | 36 | 76 | 180 | 1000 | 115 | 1 | 5 |
| (7) Workbench | — | — | — | — | — | — | — |

*The walls and ceilings of this room must provide acoustical isolation to 70 dB. The noise level in the room will be approximately 95 dBA.*

**Table IX-2. Test Equipment and Utilities in Room N-3 of Proposed CEVTL**

| Item | Measurements | | | | Electrical Characteristics | | | |
|---|---|---|---|---|---|---|---|---|
| | Depth (in.) | Length (in.) | Height (in.) | Weight (lb) | Volts | Phase | Amps | Other |
| Digital control/monitor test system | 36 | 66 | 60 | 500 | 110 | 1 | 20 | 3 circuits |
| Teletypewriter (with CRT display) | 24 | 36 | 40 | 80 | 115 | 1 | 5 | — |
| Disc/library | 36 | 36 | 40 | 80 | 115 | 1 | 5 | — |
| Power amplifier | 36 | 72 | — | 700 | 220 | 3 | 450 | — |
| Vibration generator | 60(dia | — | 60 | 1500 | 220 | 3 | 400 | — |
| Heat exchanger with pump | 24 | 24 | — | 300 | 220 | 1 | 8.5 | Chilled water, drain |
| Pressure/altitude chamber | 50 | 45 | 60 | 700 | 115 | 1 | 100 | — |
| VSP machine | 42 | 48 | — | 700 | 115 | 1 | 10 | Chilled water, drain |
| Temperature/humidity conditioning chamber (2) | 48 | 48 | 60 | 200 | 115 | 1 | 30 | — |
| Temperature-conditioning chamber (thermal shock) | 60 | 60 | 60 | 300 | 115 | 1 | 50 | |
| Work benches (2) | 36 | 72 | 32 | 200 | 115 | 1 | 15 | — |
| File cabinets (2) | 36 | 18 | 42 | 30 | — | — | — | |
| Desks (2) | 33 | 60 | 30 | 100 | — | 1 | — | |
| Storage cabinets (5) | 20 | 36 | 72 | 40 | — | — | — | |

# Chapter X.—Mechanical Fabrication

by Harry E. Hill, Jr., Guy T. Appel,
and Paul S. Flosge

## X-1. Introduction

The mechanical fabrication section of the PVF will provide general "production" support to the other PVF technological areas. This section will fabricate plastic and metal parts, tooling equipment, and fixtures; perform various types of mechanical inspection; and be responsible for the mechanical maintenance of facility equipment. The equipment includes both modern general shop equipment and some that is applicable to high-volume manufacture. The areas that make up the mechanical fabrication section are general shop, inspection, plastic molding, automated metal removal, die-casting, and powder metallurgy.

Historically, the mechanical fabrication of electronic fuze prototypes has been conducted in the HDL shops with standard, general-purpose machine tools (e.g., lathes and mills). These tools have been used since the establishment of the laboratories during World War II and, at that time, most other fuze manufacturers used similar equipment. The past 25 years have seen more extensive use by industry of new materials and processes for mass production of mechanical components. To a large extent, this change has resulted from the increasing costs of materials and labor that have spurred the development of automatic assembly equipment and material-saving processes. However, the manufacturing methods and processes for electronic fuzing have not kept pace. A major contributing factor to the increasing disparity between methods used in the manufacture of fuzes and methods used by other segments of industry is the continued use of nonproduction equipment, primarily involved in the metal removal techniques, for the fabrication of fuze prototype parts.

High-speed, material-saving fabrication processes also have not been fully utilized for the fabrication of electronic fuze components. Specifically, few die-cast or powdered metal parts are produced. These processes have, however, been widely adopted in the industrial sector for high-volume commercial production of mechanical components.

Die-casting is probably the fastest of all casting processes and is equal to stamping, die-forging, plastic molding, powder metallurgy, and screw machining for high-speed, large quantity production. Even while achieving high production rates, die-casting provides close tolerances and smooth surfaces and it can be used for complex parts having thin cross sections. Die-casting requires the following design considerations. Sections need to be uniform and thin; changes in thickness should be introduced gradually. Ample fillets must be provided and undercuts avoided. Large, thin, flat sections must also be avoided because of the possibility of warpage as the castings cool.* The most important design consideration in die-casting is the necessity of providing drafts (tapered walls) that permit part ejection from the die and removal of core rods. These design considerations, especially draft provisions, make the design and form of the die-cast part unique. The consideration of these design peculiarities must be included during the development process.

If a part is to be die-cast, the fit of that part and its mating parts must allow for draft angles, wall transitions, and allowable undercuts during the design process. If these considerations are not included during development, the use of die-casting will either be precluded or require subsequent expensive change orders resulting in increased cost and/or program delays.

Industry has increased considerably its use of powdered metal parts during the past decade. Al-

**Proper mold design is required to minimize the occurrence of porosity in die-castings.*

though the basic price for powdered metal is relatively high, its nearly complete utilization of material and the limited need for subsequent machining of finished parts make the process highly competitive with other methods. Since there is a high associated die cost, this process usually necessitates production runs greater than 10,000 parts for it to be economical. This amount is exceeded considerably by total volume requirements for most fuze programs. Again, as with die-cast parts, certain limitations are placed on the design of parts for powdered metal fabrication. Foremost, from the fuze designer's point of view, are the effects of size and shape on the density characteristics of the end product. The number of levels of a part affects the complexity of the press or results in a varied density at each level. Also, sharp radii or knife edges must be avoided. Uniform shapes can be accommodated parallel to the compacting axis, but perpendicular holes and threaded sections cannot be provided without secondary machining. Some considerations, such as restrictions on holes perpendicular to the compacting axis, are well defined; others, such as restrictions on knife edges or sharp radii, are judgements. Many of the judgements are based on the evaluation of tradeofts between part function, die life, die material, and production run quantities. Design of one component to compensate for the permitted manufacturing variations of another component, performed during the development phase, achieves a low-cost production item; at the same time, it establishes a valid Technical Data Package (TDP) and proper, reliable fuze function.

The equipment necessary for the general shop support includes lathes, mills, drill presses, grinding machines, a jig-borer, NC equipment, and gear hobs. The gear hobs and NC equipment will be used in the manufacture of mechanical components for fuzes with the remainder of the equipment used primarily to make tools and fixtures.

Cost factors and economic operation of the facility will justify the initial manufacture of components, during the early design/development phases, on equipment other than production equipment. Final design considerations will be adjusted for mass producibility of the end items as made on the production-suited machinery. The use of NC lathes, mills, and machine centers for quantities of 50 to 200 in many instances will be the best compromise. This equipment has setup times and manufacturing rates that fall between those of the production equipment and the manually operated equipment. The setup time typically is closer to that of automatic equipment, with the production rates closer to those of manually operated equipment. Parts tolerances will generally vary more when obtained from automatic equipment than will those obtained from a machinist. A machinist compensates for tool wear by gaging parts frequently and altering tool settings. On an automatic machine, the first components are set for manufacture near one tolerance extreme. As the tooling wears, the last components come off the line near the other tolerance extreme.

The inspection equipment is composed exclusively of equipment presently in operation at HDL. The inspection of dies and tooling used throughout the PVF is critical. Dimensions will be checked and values recorded at the start and after full completion of each run. All data will be entered in the computer center for later analysis. Parts will be designed so that they can be made efficiently and economically. To achieve this, not only will parts have to be made in large quantities, but tool wear and required tool changes will have to be minimized. This is implied since the replacement of tooling after several thousand pieces on a production run of hundreds of thousands increases the cost of the part. Close monitoring of tool and die wear as a function of parts produced will enable valid extrapolation of ultimate tool and die life, predicated on the information gathered in making prototype quantities on production equipment.

Statistical analysis of component size variation as a function of all facets relating to specific manufacturing methods will aid the designers in selecting the process, part configurations, and design tolerances. Similarly, early identification of parts that exhibit wide size variations from the norm will aid the designer in identifying areas of a subassembly that will require special attention. If practical, compensation for these variations would involve redesign of components; if not, another process would

have to be selected. Although part cost would be higher, first consideration would have to be functional operational reliability.

Accumulation of tool wear data will also determine the time at which tooling should be replaced, prior to the manufacture of out-of-tolerance components. To be useful, the knowledge must be gained from high-speed production equipment to enable prediction of tolerance trends that will appear in actual production. In addition, good inspection data entered as computer records will show the precise size of the components that went into prototype fuzes. These data will document the fact that assemblies that were tested were representative of the TDP.

A further benefit of close inspection during development will be the establishment of accurate gaging standards for later use in production. Detailed analysis of the size variations of parts in production will result in the use of Go/No-Go gages that are less costly and, although not as precise, are adequate test criteria and better suited for measurements on a mass production line.

The plastic molding equipment at HDL is adequate. It is felt that the equipment is, for the most part, adequate for fabricating prototype models of electronic fuzes. With this equipment there would be the ability to fabricate both thermoplastic and thermosetting plastic parts. Because of their special properties and the cost savings in the use of plastics, their use in electronic fuzes has been steadily increasing. The availability of this equipment at HDL has led to the use of new materials, the development of new plastic components, and the replacement, in product-improvement programs, of previously made metal parts by plastic parts. Much of this work has been on nose cones—the major plastic component of electronic fuzes. Currently work is being done to develop new sealing and joining methods to provide a strong, weather-tight seal at the nose-cone/fuze-body interface. Most of the development work on the plastic turbine blades for the turboalternator power supply was done at HDL.

One promising area for investigation is the use of plastic gears and pinions in S&A devices, although the plastics used must be compatible with the gases in the environment. Plastic molding promises large cost savings in this area, but advances are required to overcome the static-strength and creep-strength limitations of present materials. Also, additional information must still be developed on the applications and limitations of plastic-molded gears. A specific aspect that must be evaluated is the effect of long-term storage. For this evaluation to be done, some of the tests will have to be made in close liaison with the fuze designers. Complete testing and evaluation of the various plastics is an absolute necessity for development of valid TDP's. New plastics are being introduced continually, and unless comparisons can be readily done, the best material may not be specified. With the PVF in operation, the designer can readily have parts produced from several materials, enabling him to select the optimum material for the intended purpose.

The metal parts fabrication group consists of three types of equipment: gear hobs, screw machines, and chucking machines. Unfortunately, expensive gear hobbing is still the primary method for manufacturing gears for electronic fuzes. Some equipment being specified for the PVF will be used to develop alternative methods to gear hobbing but until these processes are developed, the facility must have this equipment. HDL does have one gear hob machine but requires purchase of a second one to provide necessary operational flexibility. Besides providing gear components for prototype models, the equipment will provide gears for use in the development of new methods of assembly and fabrication. Investigation of gear operation as a function of dimensional tolerances will aid the designer in specifying these tolerances. Permitting maximum tolerances for gears that will still perform reliably will result in fewer rejects, longer tool life, and overall lower costs.

The largest numbers of fabricated parts are probably those made by a screw machine. These machines produce parts from any machinable ma-

terial they offer production rates of up to 5000 parts per hour and they maintain high accuracy. For optimum use of screw machines the parts must be properly designed. This again requires a close working relationship between the designer and PVF personnel. Since the ultimate objective is the development of mass-producible end items at lowest cost, it is necessary that production-oriented designs be introduced at the earliest practical time. This requires fabrication of designs during prototype development, attempting small quantity production, feeding production problems back to the designer, and redesign for economical trouble-free production.

## X-2. Description of General Shop Area

The general shop area of the PVF contains equipment that will be used in the fabrication of jigs, fixtures, molds, and dies. The equipment necessary for this support activity is currently owned by HDL. The required equipment includes lathes, mills, drill presses, grinders, a jig borer, and an electrical discharge machine (EDM).

The semiautomatic assembly equipment proposed for the PVF requires the fabrication of special jigs and fixtures as tooling for the rapid, accurate location of components. These jigs and fixtures may simply be locating pins on a base plate or may be complex fixtures requiring locating, clamping, and rotating component parts.

In addition to the jigs and fixtures for the semiautomatic assembly equipment, jigs and fixtures will be required for manual assembly operations. Because of the various types of assemblies that will be produced in the PVF, these assembly aids are necessary for efficient operation.

The fabrication of all required components for a prototype fuze is not possible in the PVF on the production equipment. There will be times when scheduling restrictions or economic considerations will justify the fabrication of components on the general shop equipment. This can normally be done with the equipment listed. Equipment in HDL's general shop will also be employed as appropriate to supplement PVF facilities when higher than normal demands occur.

The molds and dies used for plastic molding, die casting, and powdered metal pressing will be fabricated in the general shop area. In addition to the standard equipment, a jig borer and EDM are necessary for this work. The jig borer will produce items requiring close tolerances. The EDM machine will be used to fabricate dies that require the use of extremely hard materials.

The grinding equipment is used primarily for tool forming. Two exceptions are the surface grinder and cylindrical grinder. The surface grinder would be used to generate flat surfaces on jigs and molds. The cylindrical grinder would be used to fabricate shafts and dowels requiring extremely smooth surface finishes.

### *X-2.1 Numerically Controlled Equipment*

Major manufacturing companies are gradually realizing that numerically controlled (NC) production equipment is not just a glamorous addition to the production floor but a real work horse. With today's high labor costs, NC equipment for many manufacturing operations is justifying its large capital expense by returning high yields. Typical examples of savings that have been experienced by the use of NC machining (NCM) are shown in table X-1. Savings are attributed mainly to the reduction of setup and parts-handling time and to the number of uninterrupted machine-cutting cycles that can be programmed on the NC machine. The cost of labor for the machine time, both conventional and NC, can be tabulated by use of the current hourly rate as the multiplication factor. With this in mind, one is safe in saying that NCM is playing an important role in the manufacture of high-volume items of which fuzes are an example. The advantages of NCM lie in the speed and accuracy of positioning, part configuration memory, planned tooling sequences, and automatic tool changing and loading performed integrally with the metal removal cycle.

Designing fuzes for NC metal removal during prototype development will be enhanced by the

ability to fabricate the part on a typical NC machine that will run through the projected manufacturing cycle. The design can be easily changed by changing the machine computer program. The designer will become intimately familiar with manufacturing processes, using a variety of NC machine configurations presently available in the HDL Engineering Support Branch. The machine configurations that will be available are as follows.

(a) Two-axis continuous-path, engine lathe with automatic tool changing capability.

(b) Two-axis, point-to-point, single spindle, drilling machine with milling capability.

(c) Three-axis, continuous-path, vertical milling machine with linear and circular interpolation in the control system.

(d) Three-axis, three-positioning, two-continuous-path, vertical drilling and milling machine with a position indexing tool turret with linear and circular interpolation for continuous-path milling.

(e) Three-axis, horizontal spindle machining center with an automatic tool changer (24-tool storage), three-linear-axis operation, and a rotary indexing table.

(f) Punching machine with a rotary automatic tool changer (26 stations).

As indicated by the above list, the designer will have turning, drilling, and milling metal removal capabilities with which to prove out his design under realistic NCM processes.

Table X-1. Time Savings from Use of NC Machining

| Item | Lot size | Conventional hours | NC hours | Percent savings |
|---|---|---|---|---|
| Switch bracket | 50 | 0.95 | 0.21 | 78 |
| Manifold | 30 | 0.73 | 0.36 | 51 |
| Gear housing | 10 | 12.95 | 1.00 | 92 |

Table X-1. Time Savings from Use of NC Machining (cont'd).

| Item | Lot size | Conventional hours | NC hours | Percent savings |
|---|---|---|---|---|
| Cylinder block | 10 | 4.05 | 0.40 | 90 |
| Bracket | 10 | 3.78 | 0.70 | 81 |
| Motor base | 15 | 2.16 | 0.65 | 70 |
| Casting | 35 | 3.18 | 0.39 | 88 |
| Panel | 10 | 2.0 | 0.22 | 90 |
| Plate | 10 | 0.9 | 0.27 | 60 |
| Bracket | 13 | 0.24 | 0.139 | 43 |
| Hub | 1 | 23.5 | 5.4 | 77 |
| Flange | 10 | 14.0 | 1.25 | 92 |
| Base | 1 | 54.3 | 11.3 | 98 |

### *X-2.2 Metal Removal Equipment*

Swiss screw machines have been used extensively in industry in the production of electronic fuze components. Their use is especially applicable to the fabrication of extremely accurate slender parts that must be made at high production rates. These machines readily cut pivot points, back shoulders, multiple diameters, tapers, and complex shapes.

The tooling on the Swiss screw machine is located circumferentially around the stock being machined. On a machine with five tooling locations, two are typically employed for diameter turning, and the remaining three are available for cutting-off operations, knurling, chamfering, etc. The stock is held by a rotating collet and advanced to the cutting tools that are controlled and positioned by cams. By coordinating their movement with the forward movement of the stock, almost any desired shape can be turned. The diameters on slender parts can be held to 0.0003 to 0.0005 in.; shoulder length can be held to $\pm 0.0003$ in.

Many standardized attachments that are available eliminate other complex secondary opera-

tions These include the following tools single point, flat, and circular form, drills, cutoff, counterbores, recessing, chamfering, milling, threading and tapping These attachments can be interchanged on a specific piece of equipment but are not usually interchangeable from one manufacturer's machine to another To minimize tooling costs and provide maximum flexibility it is best to purchase the two machines necessary for the PVF from one manufacturer However the quantities of parts to be produced in the PVF do not warrant the additional cost of automatic bar feeds

Several manufacturers provide machines that have a versatile set of extremely refined attachments. Desired tooling includes cross slides for form tools, drilling, counterboring, threading, recessing, knurling, cutoff, and chamfering The specification for all Swiss screw machines for the PVF should specify chip separators Other characteristics that should be considered in the specifications are an electromechanical index on the headstock and the accelerator headstock spindle brake, or three-cam index capability

The operating time of these machines for a specific job would be extremely short because production rates will be 500 to 5000 parts per hour The setup time for a machine can take 4 to 16 hours depending on the complexity of the part to be made Hence a good part of the time in this area will be devoted to setup rather than fabrication A machinist will require three to four weeks of specialized training to develop proficiency in setting up these machines

A manually loaded chucking machine will be required to perform secondary operations on the castings and powdered metal parts. The machine should accommodate a minimum of six tools on a basic slide and have a separate threading attachment Several NC chucking machines are currently manufactured that would satisfy the needs of the PVF If an NC chucking machine were selected, a separate threading attachment would not be needed but an eight-tool turret would be needed A typical setup time on any chucking machine is three hours for a single operation

### X-2.3 Inspection

HDL has substantial sophisticated mechanical inspection equipment that will support the PVF, particularly for measurements of small parts Much of the equipment measures linear and angular dimensions. This area will provide precise dimension information that will be necessary in setting up tolerance requirements for the PVF-produced parts Of special interest to the PVF are the Bendix Sheffield Cordax Inspection Machines These machines operate using the Cordax program run on a Digital PDP-8 minicomputer for recording positions and converting these measurements into dimensions such as height, length, width, diameter, radius, and angle The PDP-8 operates in a time share mode while running Cordax to provide general-purpose computational facilities using BASIC and other languages

On order for one of these Cordax machines is an automatic drive system with automatic probe sensing The probe will automatically be positioned on a part to measure any number of desired dimensions With this system, a running inventory of all prototype parts and dimensional characteristics sent through inspection will be logged into the computer, reflecting part dimension changes during the prototype run. Computer program analysis of these data records will be extrapolated to project these changes to forecast tool life and other useful production-line information During prototype development, the data in computer storage will be analyzed along with other test data to statistically correlate fuze performance and part dimensional characteristics

### X-2.4 Plastic Molding

The two broad classifications of plastic materials are thermosetting and thermoplastic compounds.

*Thermosetting* compounds produce a product that takes form and a permanent set within a mold by simultaneous application of heat and pressure The compound is presoftened by heating and then

hardened by polymerization through the application of additional heat and pressure

*Thermoplastic* compounds, however, undergo no chemical change in molding Thermoplastics are softened at elevated temperatures and remain soft until cooled

Plastic materials differ widely from one another, even within the two specific categories Their individual characteristics adapt to many processing methods compression molding, transfer molding, injection molding, jet molding, casting, extrusion blowing, and laminating All the plastic materials can be fabricated by more than one method, although one process is usually much better than the others Compression, transfer, and injection molding are the three processing methods that are most often used in fabricating electronic fuze components The molding material is purchased commercially in powder or granular form However, two processes, compression and transfer molding, require preforming of the plastic This preforming compresses the powder into pellets of uniform density and weight The size and shape of the pellets are related to the size and shape of the mold cavity that will be used in the final operation The advantages of preforms are to facilitate rapid loading, minimize waste, and negate the possibility of mold damage due to overloading Two types of preforming presses exist rotary and reciprocating A rotary press is a multi-stage multi-die machine that produces items at a high rate Pellets produced on the rotary press have the same characteristics as those produced on reciprocating machines The reciprocating machines have a much lower output rate but they require only one die, and dies can be changed quickly This is a distinct advantage in prototype fabrication, with its multiple programs and frequent design changes Changeover requirements, the need for fewer dies, and less emphasis on high rate production dictate selection of the reciprocating machine for the PVF The proper choice of presses for industrial application is not as obvious

Compression molding is the application of a compressive force to a premeasured amount of material in a heated mold As the mold closes, pressure is applied to the softened material, forcing it to flow and conform to the shape of the mold. The initial material may be either granular or a preform Thermosetting compounds are normally used, since the required rapid heating and cooling of the mold makes a thermoplastic compound less suited to this process Pressures normally used in compression molding are between 100 and 8000 psi, depending on the material and size of the part The temperature range of the molds is from 250 to 400 F (about 121 to 204 C) and is achieved either by directly heating the mold or by heat transfer from heated platens The heat is supplied by steam, heated liquids, electrical resistance, or ultra-high-frequency electric currents

Presses for compression molding fall into three categories hand operated, semiautomatic, and automatic Automatic presses are required on production lines to meet high-volume output rates The parts produced on automatic presses are quite uniform because timing and feeding of raw materials is highly repetitive and automatically controlled Semiautomatic presses operate automatically for one cycle, but then require manual loading and unloading The automatic cycling of the molding process on a semiautomatic press eliminates some operator-induced variations The use of preforms on a semiautomatic press aids the production of uniformly similar parts that duplicate those produced on an automatic compression molding press

The semiautomatic press is best suited for the PVF It produces parts which quite accurately duplicate parts produced on automatic presses It will require no additional investment because HDL currently has this capability If the increased emphasis on prototype validation at HDL causes an increase in the demand for compression-molded parts, the addition of automatic controls would be considered The addition of automatic controls would allow higher production rates without expansion of current staff

Transfer molding differs from compression molding in that the molding material is initially in a

pressure chamber above the mold cavity The material is plasticized by heat and pressure and slowly injected into the mold cavity where it is cured and hardened Transfer molding is excellent for production of parts having intricate shapes and large cross-section variations The process is also useful for parts that require small metal inserts, since the hot plastic enters the mold slowly, at low pressure This process differs from injection molding of thermoplastic materials in that the mold is kept heated at all times and parts are ejected without cooling HDL currently operates several presses of this type, ranging from a manually operated 100-ton hydraulic press to several 30-ton semiautomatic presses The existing capabilities are considered adequate for the PVF operation

Injection-molding machines have the highest production rates, up to 350 shots per hour This production rate allows the use of single-cavity molds and reduces molding costs The operation of these machines is the same for thermoplastic and thermosetting compounds The molding compound is contained in a hopper and fed by gravity into a metering device This measured charge is then heated in a heating chamber that operates at 250 to 500 F (about 121 to 260 C), depending on the material used and the mold size The heating chamber contains a torpedo-like spreader that causes a thin layer of material to be heated rapidly and uniformly The ram moves forward to inject the plasticized material at pressures as high as 30,000 psi Thermoplastic materials are generally used in injection molding They have low material loss since the gate and sprue material are reused The mold is maintained by circulating water at a constant temperature selected at 165 to 200 F (about 74 to 93 C) Since it is not alternately heated and cooled the production rate may be two to six shots per minute a significant increase over compression molding HDL currently operates several injection-molding machines

An additional injection-molding machine of 1-oz capacity should be purchased This would replace the two 1-oz manual-control presses currently in operation The new machine would be semiautomatic, with temperature and pressure controls, including low-pressure injection A typical press of this type is the Hornet Model HVI-25RS, manufactured by Newbury Industries

HDL currently has enough auxiliary equipment to support the plastic molding area It includes a rolling mill, plastic grinder, tablet maker, and several heat exchangers for both heating and cooling molds

### X-2.5 Die Casting

HDL has no capability for die casting at this time Die casting is also an area where considerable interest has been indicated by several in-house groups particularly the safety and arming (S&A) group There have been difficulties in securing prototype parts and there is a desire to be more intimately involved with the process than is possible when dealing with contractors The lack of any capability in this area greatly affects equipment choices, and tends to make decisions divisible into the categories of immediate minimal needs and additional, more advanced equipment

For the most part, two basic types of alloys are used in die-cast fuze parts They are aluminum and zinc alloys This causes a basic problem since each material requires a different type of die-casting machine The hot-chamber die-casting machine is used for zinc, and the cold-chamber die-casting machine is used for aluminum Molten aluminum, because of its higher temperature and reactivity, tends to attack the steel pumping mechanism of a die-casting machine, which thus requires special construction A cold-chamber aluminum machine requires that the molten aluminum be transferred into the pressure cylinder from a separate melting pot for each machine cycle By contrast, a hot-chamber die-casting machine has the pressure cylinder immersed in the melting pot so that no molten metal transfer is needed The zinc melting pot is therefore an integral part of the die-casting machine The advantage of a hot-chamber machine is that no separate melting apparatus is required and, because no metal transfer is involved, cycle times on a hot-chamber machine are faster. Zinc can be used and parts cast in a cold-chamber machine if

need be, but aluminum cannot be used in a hot-chamber machine Therefore, all other considerations aside, it would seem that a cold-chamber machine would be the type to purchase

There are, however, other important considerations First, most of the die-cast parts (which tend to be small) are zinc, and zinc is the easier metal to work with overall Second, the cold-chamber machines generally come in larger sizes than hot-chamber machines This difference further compounds the initial inefficiency of fabricating zinc parts in a cold chamber Therefore, the more practical equipment with which to start die casting would be the hot-chamber zinc die-casting machine This machine could be included with the initial PVF equipment procurement, or it could be added in the future Additional equipment would later include a larger cold-chamber aluminum die-casting machine and a melting furnace

Another process in die casting requires trimming flash from the castings This can be done several ways First, there are die-casting machines that incorporate a trimmer in their design Another way of trimming is to use a trimming press The flash can also be trimmed by various methods manually if necessary It is preferable to secure a press with a trimmer included If this is not possible, a press would have to be purchased separately, since a relatively large number of parts have to be trimmed If two die-casting machines are purchased—one cold chamber and one hot chamber—the probability of having an integral trimmer on both would be very small, so a trimming press should be viewed as an eventual necessity

The maximum number of die castings of any one part produced through all stages of development will be 5000 The total monthly output of die castings of all parts should not exceed 3000 pieces The maximum part weight is about 4 oz, although most parts will be only a small fraction of that weight

A relatively new phase in die casting is injected metal assembly The two parts to be joined are held in a die and holding fixture, and molten zinc or lead alloy is injected into the cavity The spherical shrinkage of the injected metal provides a mechanical locking of the parts Because the process does not rely on adhesion or bonding, there is no need for special cleaning and surface preparation Parts that can be joined can be made of glass, brass, aluminum, steel, and nylon. The advantages of this process are high speed (up to 1100/hr), uniformity of assembly, relaxed tolerances for individual parts, no finishing operation required, and elimination of the effect of operator skill on the quality and strength of assembly.

In addition to the joining of parts, the operation can include the integral forming of parts by use of special dies to form cams, flanges, or pinions in the same process Where accuracy is important, tolerances can be held to 0 0005 in. total indicated runout (TIR) Tolerances have been held to 0.003 TIR during the assembly of a brass gear to a shaft while molding the pinion The volume of metal that can be injected limits the size of assemblies Current equipment is limited to 0 6 in $^3$ of molten metal.

Because the fixture positions each part independently, tolerances on parts can be relaxed The strength of the joint does not depend on precise dimensions of the component Parts held together by this process rely on radial and axial shrinkage Porous materials provide ideal locking surfaces because the injected metal penetrates the voids to provide the positive lock. For smooth-surfaced materials, some provision must be made in the design for gripper areas into which the metal can contract This can be provided by annular grooves, dovetails, or knurling

A list follows of the equipment needed to support a die-casting facility

### Minimum Equipment Needed

Hot-chamber zinc die-casting machine (1), 3.5 to 12 0 oz.

Injection assembly machine (1)

Trimming press (1), 2 ton

### Additional Equipment Desired

Cold-chamber aluminum die-casting machine (1) 12 to 25 oz

Melting/ladling furnace (1)

Tumbler/deflasher (1)

### Materials

Aluminum and zinc ingots die lubricant, abrasives, etc

Die-casting molds

## X-2.6 Powdered Metal

### X-2.6.1 Introduction

A capability for the in-house production of small quantities of powdered metal parts would aid the fuze development programs at HDL. At the present time, only a small percentage of the metal parts that could be made using powdered metal are being made by this process. A substantial savings in the cost of mass-produced fuzes would be realized if the powdered metal process were being used to fabricate fuze parts

Not having an in-house facility, HDL has not been able to take advantage of and use powder metallurgy during the prototype development of a fuze. It is careless to specify a powdered metal part design if it has not been thoroughly tested and evaluated before the release of a TDP. Tests conducted on similar parts made of machined powdered metal slugs or bar stock will not indicate precisely how the powdered metal part might perform. It is possible to secure some off-the-shelf powdered metal parts from commercial sources, as has been done with some present parts, but the development of each new part has its own intricacies and tends to be one of a kind. Some exposure to the powdered metal design process has provided gradual acquisition of knowledge but does not compare to the expertise that would accrue from actual experience in an in-house facility

A basic inherent problem in securing small quantities of powdered metal parts from outside sources is the operation of the commercial marketplace. Purchase of any prototype part is costly. It is made more difficult for powdered metal parts because of the additional special compacting-press tooling required. First, this type of tooling reduces the number of available competent contractors. Since there is no guarantee that a prototype part will go into volume production, the risk factor for a profitable return is high and further discourages potential part suppliers. But even when a contract is let, there is high probability that the prototype part design and possibly even the tooling will have to be modified. Transaction with a supplier then requires placing a new contract or renegotiating the original contract—both costly exercises

Scheduling requirements and program funding do not allow a designer the luxury of even considering a new contract or the renegotiation of the original contract. Rather than go through the aforementioned process, the designer must rely on materials and designs that use in-house capabilities

Thus, a part that obviously called for use of powdered metal would be fabricated for the prototype using some other manufacturing process. However, in setting up a production line, a contractor would naturally attempt to reduce costs by fabricating the part out of powdered metal. This would often require redesign of the part (as a change cost) and result in a fuze that was somewhat different from the actual validated prototype fuze. In some instances, functional performance would be adversely affected, introducing costly shutdowns and requiring expensive retesting, revalidation programs

The types of parts that are often made of powdered metal in industry and that would probably also be used extensively in HDL programs include the following gears, sprages, pawls, shafts, bushings, plungers, base plates, housings, and other component parts used in small, clock-type control and timing mechanisms. At the present time, a few of the more standardized smaller and simpler fuze

components of this type are being made from powdered metal by outside contractors.

It is expected that the demand for any particular part would extend up to a maximum of about 5000 units in any particular development program. At any given time there may be between two and five parts being developed in powdered metal. In a typical month, the total production of all parts would not exceed 3000. The total number of parts produced will be divided between one or more trial runs. Units would be used to check the basic design, to determine dimensional variations, and to provide parts for various types of environmental, strength, and operational testing. A longer run of the final prototype design would provide additional units for a repeat of the preceding tests, for test and evaluation of subassemblies, and for tests of completely assembled fuzes. A series of trial runs could be required before an acceptable part would be produced. A general trial run would be on the order of 100 to 200 units, and a final run could produce up to a few thousand. Although all parts made would be inspected closely, only a small number would be used in the various detailed tests. A total of no more than 5000 of a specific part would be made between trial and final prototype stages.

The low unit cost per part, coupled with the fast cycle times of the required presses and furnaces, makes a long run practical for checking the press operation and part reproducibility. With a press that can produce 10 to 40 parts per minute, several hundred parts can be made very quickly to check for such things as powder filling and uniformity of compaction. The inherent design of these powdered metal presses makes fast cycle times possible, but it also makes such detailed checking necessary for setting up part design processing procedures.

The large runs of parts can also be handled quite easily by the sintering furnaces that are available. Except for the small batch furnaces that are not really related to production furnaces, the remaining suitable furnaces have capacities similar to the general range of the presses. These larger furnaces also make it practical to use atmosphere equipment corresponding to that used in the production furnaces. With the larger furnaces and their associated atmosphere equipment, it will be possible to make realistic determinations of the production variables that will prove useful to the ultimate fuze contractors.

### *X-2.6.2 Powdered Metal Processes*

Production of powdered metal parts involves several separate processes. First, a powder of the desired composition must be produced. Then this powder is pressed into compacts of the desired shape in the "green" state. These green compacts are then heated until their powder particles are bonded together. After this heating or sintering process, the part may be used as is or it may go through some combination of repressing, sintering, and impregnating to produce the desired physical properties. Final machining may be required, depending on part complexity.

The processes naturally dictate the equipment required for a powdered metal facility. The equipment falls into three basic operations—blending, compacting, and sintering. Each of these operations requires its basic tools—the mixer, the press, and the furnace, plus the related ancillary equipment. A further description of some of the basic processes involved follows.

*Blending.*— The first step in producing a powdered metal part is to secure a powder of the desired composition. The blended powder usually consists of either an alloy powder, a mixture of elemental powders, or a single elemental powder, together with a lubricant/binder, such as zinc stearate. This lubricant/binder reduces die wall and interparticle friction. It also makes the powder more workable before pressing and helps to hold the green compact together.

*Compacting.*— After the desired powder is secured, it can be compacted by several types of presses. The three basic types of presses are the isostatic, the hydraulic, and the mechanical. The isostatic press uses a flexible mold, which is subject to hydraulic pressure over its entire outer surface to

produce the compacting force. With this type of press, it is easy to achieve uniform, homogeneous, high-density parts. There is a problem in designing and securing the required flexible molds. The pressure produces compaction from all directions simultaneously, which makes the calculation of the mold shape somewhat difficult. These presses are also quite slow and difficult to operate, so they would not be used in volume production. Therefore, use of such a press in house would make it difficult to relate our experience to that of the final fuze manufacturer.

There really is no clear choice between the other two types of presses. Although the method of producing the compacting force is entirely different in the two presses, their operation is nonetheless quite similar. Mechanical presses use an arrangement of cams and levers to produce this motion; hydraulic presses use hydraulic cylinders to produce this motion. Both can be used to compress to constant density (by use of constant pressure). However, it is doubtful that this feature would be used very often.

Both the mechanical and hydraulic presses produce compaction along a single axis but there is usually more than one compaction (motion) along this axis. If a uniform density is desired over the entire part length, multiple ram motions are required. For a single-level part, compression from one side only against a die will produce a density gradient from the punch face to the bottom of the die. Therefore pressing from top and bottom is a requirement. If a part has more than one level, a separate punch with independent motion will be required for each level. These separate punches are required so that there will be an equal compression ratio in each level of the part. This equal compression ratio is needed to produce equal density in each level because powder does not flow hydraulically between levels. In a forming operation of this type, use of a hydraulic press can be an advantage. A hydraulic press can often make it easier to have multiple punches, and it is easier to control and alter the motions of these punches.

Two features available in both mechanical and hydraulic presses are removable die set tooling and tooling operating on the withdrawal principle. Both features are highly desirable and often come together. A die set is a removable tool holder and tooling set which can be set up independent of the press. This allows tooling to be set up or repaired while the press is being used with another set of tooling. The setting up of tooling is usually much easier on a work bench than in the confined spaces of the main press frame. An additional advantage of die set tooling is that it holds tolerances more precisely because the punches and die are held in alignment by their own frame. This scaled-down frame holds its alignment far better than the large press frame, which also has to take the loads of producing and applying the compacting force.

Normally, the upper punch retracts from the die, allowing the die to be forced up by its float springs from the lower punch. The lower punch then moves up and presses the compact out of the restrained die. This rebound motion leaves the compact unsupported in the die, often causing cracks. Withdrawal tooling reduces the possibility of breaking compacts when they are removed from the press. In withdrawal tooling, the die is not spring loaded so the lower punch remains in contact with the compact. The upper punch can rest on the compact as the die is withdrawn as an extra protection against crack growth.

*Sintering Operations* — Sintering consists of heating the green compact in a controlled reducing atmosphere to a temperature below the melting point of the base metal. The required temperature varies widely, depending on the material being used. Powders of iron and copper bases require a much higher temperature than those of aluminum bases. At the sintering temperature, a predominantly solid-state bonding process occurs between the powder particles of the compact. It is this bonding that determines the mechanical and physical properties of the part. After cooling, the part may be used as is or it may go through further operations to develop its properties. These could

include repressing, resintering, impregnation, or infiltration Both resintering and infiltration involve the sintering furnace

The basic tool for the sintering operation is a furnace that produces a high temperature, somewhat below the melting point of the metal powder Because it is desired that aluminum-, copper-, and iron-based powders be used at various times, there will be a large difference in the specific furnace temperatures required Although there will have to be a compromise in the design of the furnace, it should be optimized for the most widely used powders those of iron and copper base Both have similar temperature and atmosphere requirements A furnace of this type would also be able to handle aluminum, although it would do so at a substantial sacrifice in performance when compared to one designed specifically for aluminum

Any production rate above the purely one-of-a-kind part requires an in-line type of furnace This type of furnace features a long tube, enclosing a selected gaseous atmosphere, with an input end, a burn-off heat zone (optional), a sinter heat zone, and a cooling zone The ends of this tube are sealed by doors from the outside air to retain the control atmosphere These doors have a burn-off port and pilot to provide a controlled atmosphere outlet They also have a flame curtain to prevent combustible atmosphere from mixing with room air when they are opened to put in and remove parts

The purpose of the two heat zones is to (1) first burn off the volatile powder lubricants and binders at a low temperature, and then (2) sinter the part at a higher temperature, just below the melting point of the metal powder The burn-off furnace enables a higher production rate because the heat load is taken up by two furnaces It also allows a more favorable temperature for burn off than that of a sintering furnace However, at the low production rate proposed here, it would not be worth the added expense of the burn-off furnace

Several reducing atmospheres could be chosen for use in the sintering furnace These atmospheres include bottled hydrogen, cracked fuel gas, and dissociated ammonia; the latter two require generating equipment. Several considerations make dissociated ammonia more attractive than the other atmospheres

Cost, storage, and handling problems are encountered when bottled hydrogen is used as an atmosphere Bottled hydrogen costs more than dissociated ammonia, even when the total costs of producing the dissociated ammonia (cylinder ammonia, electric power, maintenance, and amortization) are included Also, one 150-lb (about 67 kg) cylinder of ammonia produces the same volume of atmosphere as 34 cylinders of hydrogen, so that storage and handling of the latter becomes a comparatively large problem At the proposed operating rate, it would mean that 34 cylinders of hydrogen would have to be handled each month as compared to only one cylinder of ammonia Use of bottled hydrogen is also disadvantageous considering the labor involved in changing cylinders and the problems of delivery into a restricted area

Cracked fuel gases (exogas and endogas) are atmospheres rich in hydrogen and carbon monoxide as reducing agents However, several problems make these gases undesirable as atmospheres The gas generators require a natural gas supply that would be questionable at best in terms of availability These atmospheres also contain impurities which are detrimental to the surface of the powdered metal part The range of flow rates through these atmosphere generators is somewhat restricted compared to the dissociated ammonia generator, and the homogeneity of the output gas tends to be variable with flow rate

Dissociated ammonia is produced by heating anhydrous ammonia ($NH_3$) in the presence of a catalyst to crack it into nitrogen ($N_2$) and hydrogen ($H_2$) The output gas has an approximate composition of 75-percent hydrogen and 25-percent nitrogen, with traces of undissociated ammonia This atmosphere has almost the same effect as pure hydrogen, since the nitrogen is basically inert It is somewhat superior to hyd[illegible] in terms of fewer harmful impurities and [illegible] [illegible]ewpoint

An additional advantage of a dissociated ammonia atmosphere generator is that a hydrogen diffusion unit could be added to produce ultra pure hydrogen as an atmosphere The hydrogen diffusion unit uses a palladium silver alloy as a diffusion medium to separate hydrogen from other constituents of the input gas This arrangement would require excess capacity in the initial ammonia dissociator because, on a volume basis, the yield ratio is about two thirds of the dissociated ammonia input

*Model Powder Metallurgy Facility* — The equipment listing that follows describes a model powder metallurgy facility at two levels of operation One level would be for the minimum amount of equipment required to start such a facility This equipment, by its inherent nature, would take care of all but the largest powdered metal parts to be encountered at HDL The additional equipment, for a higher level of operation, would include a larger press to handle the larger parts, a second oven for the sintering of aluminum parts, and an ultra-pure hydrogen generating unit Along with this equipment would go the increased storage and handling equipment required

**Basic equipment**

Compacting press, 15-ton capacity, 72 in long by 40 in wide by 93 in high, 7100 lb, 440 V, 3 phase, 55 hp

Die sets, spare

Sintering furnace, 30 lb/hr capacity, 180 in long by 54 in wide by 66 in high, 440 V, 3 phase, 25 kW

Ammonia dissociator, 300 cfh capacity, 60 in long by 36 in wide by 72 in. high, 440 V, 3 phase, 9 kW

Atmosphere control equipment

Infiltration chamber

Powder blending mill

Part storage cabinets

**Additional equipment desired**

Compacting press, 40- to 60-ton capacity

Sintering furnace, aluminum parts

Ultra-pure hydrogen generator plus ancillaries

Additional storage and handling

## Chapter XI.—Computer Support for the Prototype Validation Facility

by Robert H. Rosen

### XI-1. Introduction

A number of areas within the PVF require computer support. This support will be provided by a combination of minicomputers and intelligent terminals that will be acquired for the PVF, and by various types of computers and process control equipment planned for or already present at HDL. For example, the latter equipment includes the Direct Numerical Control Master Systems Controller (DNC-MSC), which supports the Research and Engineering Support Laboratory (RESL), the general-purpose laboratory-wide automation network (SPEAR), and the large-scale HDL central computer system operated by the HDL Management Information Systems Office (MISO). This combination of equipment will be referred to throughout this chapter as the "System."

An important feature of the computer support is the use of a common data base of information describing the devices and components that pass through the PVF. This information will be used and updated by the various computer applications in the PVF. Thus, the status of devices and data on the devices will be available, in a central location, as input to a variety of application programs used both inside and outside the PVF. The use of these data outside the PVF is not addressed in this chapter. Some of these outside applications will obviously be improvement of fuze designs (fuze operation as well as fuze producibility), documentation, drawings, technical data packages (TDP's), manufacturing methodologies and techniques, etc., but this material is beyond the scope of this chapter.

In the following sections of this chapter, the classes of applications that will be supported are described and typical applications are discussed. Appendix XI-A shows specific uses to be made of this support by the facilities in the PVF. Appendix XI-B is a bibliography of some articles and texts which provide information on the use of computers in computer-aided design (CAD), engineering, testing, and manufacturing.

### XI-2. Data Entry, Transmission, and Collection

The System must be able to accept data from a number of sources. The sources can be roughly classified into three areas: data entry, computer transmitted data, and automated data collection.

Manual data entry will be used whenever it is necessary to enter data into the System which are not in machine-readable form. Typical applications would include incoming inspection, in-process manual inspections, directives to the System, etc. For the most part, the input device will be similar to a teletypewriter. However, in some cases it will be a special device which is designed for a specific function (e.g., where only numeric information is to be input, the "terminal" would have just a numeric key pad). Another important data entry device will be graphical in nature. This will include both digitizers and graphics terminals. The graphics terminals will generally be used to facilitate the analysis performed on devices passing through the PVF.

Data on the devices within the PVF will reside within a number of different computers, some inside and some outside the System. The data will be transmitted to that computer on which it is most appropriate for the work to be performed. The two machines within the System that will primarily be responsible for the switching and transmission of the data will be the communication front-end controller of the SPEAR Network and the DNC-MSC of the RESL.

The automated data collection portion of the System will be used to acquire real-time data on devices as they pass through various portions of the PVF. The data collected will generally be used in

the PVF for two purposes (a) to provide control of a process being carried out in the PVF (e g , the weighing and sorting of the components of thermal power supplies), and (b) to collect data on items under test for subsequent analysis, quality control, and simulation studies For example, the stability and repeatability of S&A control parameters could be monitored, and resulting data could be used to control the fabrication of additional prototypes Simultaneously, the data could be used as input into reliability studies

## XI-3. Design, Analysis, Simulation, and Management Information

Most of the "raw computer power" that the PVF will require will be used for the design and development of "production methodologies based on the prototype engineering design and on the preliminary TDP's, the analysis of data generated during the simulated "production' runs, the design of device tests and the analysis of the resulting data, and the performance of computer simulations of the real production process It will also see considerable use in providing information to management on the status of devices and programs within the PVF Most of the CAD, analysis, and simulation will be done on the main HDL computer system Most of the data translation and temporary storage will be done on the DNC-MSC Some typical tasks which will be performed are set forth below

After the design of a device has been perfected and initial prototypes have been tested, it will be necessary to determine those problems that may arise during production of the device by industry Using the engineer's design data and information from the preliminary TDP, computer programs will be run that will control the various machines in the PVF by use of computer-aided manufacturing (CAM) techniques These computer studies will determine potential manufacturing problem areas For example, NC parts programmers will use the drawing data and the APT computer program to control the NC machines producing mechanical parts Work flow studies will be conducted to determine the best order and procedure for mechanical parts manufacture As parts proceed through the PVF, generated data will modify the work flow design Problem areas will be isolated and changes will be made to the manufacturing procedures that will eliminate the difficulties The results of this effort will be guidelines to the industrial manufacturer that will expedite setting up production lines with a minimum of problems and/or delays in producing reliable fuzes at lowest cost

Devices are evaluated in three phases—the test design, the test and the analysis of test data Various design-of-experiments computer programs will be used to develop statistically sound tests (e g , Probe Test, Random Balance Test) Specialized computer programs will be used to develop the detailed procedures for performing the tests Testing will usually be monitored and controlled by local mini- and microcomputers and by the distributed intelligence in the SPEAR network Data generated by tests performed outside the PVF (e g , at remote test sites) will be transmitted via the SPEAR network into the common data base. After tests are completed, other programs will be used to analyze the data and pinpoint weaknesses in the "manufactured" product

Simulation of the complete manufacturing process will be a major computer support task for the PVF Using data from each of the stations within the PVF and a simulation program w[illegible] in an appropriate language (GPSS or Simscript) the high rate production process will be simulated Results of the simulation will be used to "tune' the process so that final recommendations to manufacturers will indicate the best process of several presented alternatives

The use of the System to provide current, detailed information is a capability that will enable management to exercise better control over programs being conducted in the PVF The exact nature of the reports will depend on the type of information desired However, one prediction can be made—much of the output will be presented graphically Management is usually more concerned with overall trends and levels than specific

numeric values Graphics is the best way to present this type of information The computer programs that produce the reports will be nonprocedural, user directed, i e , there will not be a fixed report output format The user will be able to direct the program in a simple, English-like language Statements like

PLOT NUMBER OF REJECTS VERSUS CONVEYOR SPEED

will be used

Another important management tool will be resource scheduling Because the PVF will not be an intensive use, high-volume manufacturing plant, many of its facilities and much of its equipment (e g , rotary tables, nonsynchronous transfer lines, etc ) will be shared among the activities in the PVF By the use of an appropriate shop scheduling program, the use of these resources will be scheduled to minimize disruptions and inefficiencies

## XI-4. Equipment Requirements

The exact configuration and amount o computer-like equipment that will be required depends to a great extent on the exact makeup of the operations, equipment, and facilities within the PVF However, certain pieces of equipment will be used independent of the precise makeup of the PVF A majority of the requisite computer resources will exist before the PVF is implemented This set of equipment is listed in section XI-4 1 Some additional equipment will be acquired specifically for use in the PVF This latter equipment is listed in section XI-4 2

### *XI-4.1 Existing and Available Computer Resources*

The following computer resources are on hand and accessible at HDL.

- IBM 370/168 computer
- Direct Numerical Control—Master Systems Controller PDP-11/Adage GP430 graphics system
- Computer Vision Design System (2)
- Interdata 80/Adage GP420 graphics system
- Tektronix 4015 DVST graphics terminal
- Imlac PDS/4 graphics terminal
- SPEAR low-speed Data Acquisition, Test, and Control (DATAC)/Graphics system
- SPEAR medium-speed DATAC system
- Assorted SPEAR time-sharing teletypewriter terminals

### *XI-4.2 Required New Computer Resources*

The following computer resources are required to support the HDL PVF.

- SPEAR high-speed DATAC's (2)
- SPEAR low-speed DATAC's (6)
- Limited distance modems (10)
- Input terminals (3)
- Additional Adage computer-aided design terminal
- Microprocessor controllers for computer-aided manufacturing
- Miscellaneous probes, interconnection devices, etc.
- Computer software

## XI-5. Alternatives

The alternative to providing complete computer support for the PVF is to use only the existing equipment (sect XI-4 1) which, although extensive, lacks the hardware connection and software support for the PVF set forth previously. Without this connection and support, the automated activities, the analysis, the simulation, etc , described before will be greatly curtailed in some cases and impossible in most cases None of the automated links, the on-line data bases, or the real-time data acquisition will be performable. Thus, the advantages that could be realized by full use of computer support will not be achieved and the potential benefits to the various programs will be severely restricted

It should be recognized that the existing equipment and capabilities were not implemented for the PVF but were acquired for other support The augmentations recommended will enable the PVF to make use of the existing HDL capabilities;

thus, the PVF will have the advantages of a modern, multimillion-dollar computer support system at a fraction of that cost

## XI-6. Conclusion

In order for the PVF to be effectively used, it is necessary that this facility have adequate computer support. HDL, as part of its ongoing mission, has implemented a system to provide extensive computer support for the various laboratory organizations and their personnel. Extending this support into the PVF will increase the usefulness and greatly improve the effectiveness of the PVF.

## Appendix XI-A.—Applications of Computer Support within the PVF

### *XI-A.1 Introduction*

Given below are descriptions of some specific applications of computer support within the PVF and within facilities directly associated with the PVF. Information is also given on computer applications that are outside the scope of the PVF, but whose results are related to the activities of the PVF.

### *XI-A.2 Electromechanical Facility*

(a) Detecting and controlling the positioning of parts during assembly

(b) Controlling the testing of electromechanical modules and acquiring S&A variable and attribute data

(c) Analysis of test data

(d) Quality assurance control of electromechanical fabrication

(e) Kinematic studies of mechanisms.

### *XI-A.3 Semiconductor Prototype Fabrication and Validation*

(a) Control of the testing of integrated circuits (IC's) under electrical and environmental stress

(b) Analysis of test data

(c) Computer-aided design and layout of IC masks

### *XI-A.4 Power Supplies*

(a) Automated testing of power supplies and analysis of test results

(b) Controlling and monitoring assembly of power supplies

(c) Automated control of weighing and sorting of the elements of thermal power supplies

(d) Controlling assembly of air-driven power supplies

(e) Computer-aided design of masks of fluidic power supplies

### *XI-A.5 Printed-Wiring Boards (PWB's)*

(a) Computer-aided routing and layout of PWB's

(b) Numerically controlled drilling of PWB's

### *XI-A.6. Electronic Board Assembly*

(a) Controlling robots and other automated assembly equipment

(b) Automated testing of electronic subassemblies and analysis of collected data

### *XI-A.7 Automated Fabrication of Thick Film Circuits*

(a) Computer-aided circuit design, layout, and artwork preparation

(b) Computer control and monitoring of circuit fabrication

(c) Computer control of laser resistor trimmer.

(d) Computer monitoring of material inventory

(e) Computer testing and quality assurance (QA) of incoming material

(f) Computer-aided testing of thick film circuits

### XI-A.8 Automated Fuze Assembly

(a) Computer scheduling and controlling of nonsynchronous transfer lines

(b) Control of robots and other pieces of assembly equipment

### XI-A.9 Fuze Testing

(a) Automated data acquisition from fuzes under test and analysis of the test results

(b) Automated test setup using robots to position fuze, connect to tester, and remove after test

### XI-A.10 Environmental Validation Laboratory

(a) Computer-aided design of environmental stimuli

(b) Computer-controlled testing, data acquisition, and analysis

### XI-A.11 Mechanical Fabrication

(a) Computer-aided design of mechanical parts, molds, jigs, etc

(b) Numerically controlled machining of parts, molds, jigs, etc

(c) Computer-aided inspection and quality control of fabricated parts

(d) Computer control of stock inventory

### XI-A.12 Management Control and Aids

(a) Computer-generated status reports

(b) Computer-aided planning studies

(c) Simulation of manufacturing methodologies and techniques

(d) Resource scheduling of PVF facilities

## Appendix XI-B.—Selected Bibliography

The following is a brief sample of articles and texts which provide information on the use of computers in computer-aided design, engineering, testing, and manufacturing. Many other articles can be found in such magazines as *Datamation, Computer Decisions, Infosystems* and *Spectrum*


*APT/NC Project Session Reports*, SHARE XLIV Proceedings (1975)

Boris Beizer, *The Architecture and Engineering of Digital Computer Complexes*, Plenum Press (1971)

C H English, *Interactive Computer Aided Technology Evolution in the Design/Manufacturing Process*, MacDonnell Douglas (1975)

*Computer Aided Design and Engineering Posture and Plans*, Harry Diamond Laboratories (1974)

R M Flygare, *CADM, Lockheed's Computer Aided Design and Computer Aided Manufacturing System*, Session L-522, SHARE XLVI Proceedings (1976)

*Graphics Projects Session Reports*, SHARE XLII Proceedings (1974)

F W Karasek and R F. Karasek, *Data Systems for Instrumental Research*, Research and Development (December 1974)

James Martin, *Design of Real-Time Computer Systems*, Prentice Hall (1967)

Lawrence O Neill, *Interactive Tolerance Analysis with Graphic Display*, Proceedings of the Spring Joint Computer Conference (1969)

Hardy J Pottinger, *Considerations in the Design of a Network of Minicomputers*, PhD Thesis, University of Missouri-Rolla (1973)

H Walter Price, *The Probe Test—A Philosophy and a Technique*, Transactions of the Rochester Society for Quality Control Conference (1965)

H W Price and R H Rosen *Data Automation Requirement*, Harry Diamond Laboratories (1971)

M David Prince, *Interactive Graphics for Computer Aided Design*, Addison Wesley (1971)

*Proceedings of the 11th Design Automation Workshop*, IEEE/ACM (1974)

*Proceedings of the 9th Design Automation Workshop*, IEEE/ACM (1972)

Robert Rosen et al, *The SPEAR Report*, Harry Diamond Laboratories (1973)

James D. Schoeffler, *Minicomputer Real-Time Executives*, IEEE Compucon Tutorial (1974)

Edward Yourdon, ed , *Real-Time Systems Design*, Information and Systems Institute (1967)

## Chapter XII.—Planning and Progress

by Harry E Hill, Jr.

After the initial formulation of the PVF concept it became apparent that the question of Government or company operation would have to be decided early, because of the need for certain basic support activities and choice of geographical location. After preliminary examination, Hamilton Technology, Inc., Lancaster, PA, emerged as the best choice for a company-operated facility Hamilton was geographically desirable because of its closeness to the fuze developers Hamilton possessed GOCO facilities that were not in use and were available. Furthermore, Hamilton was experienced in fuze fabrication and assembly The choice for Government operation was the Harry Diamond Laboratories This would place the fuze designers and prototype fabrication close to each other and also would allow the use of the current facilities at HDL for prototype fabrication and necessary support activities An economic analysis showed the construction and operation of the PVF at the HDL site at Adelphi, MD, the better choice. The HDL location and Government operation shows a discounted total project cost advantage of 4 ⁻ million dollars for the seven-year economic life used and is further supported by the nonquantifiable benefits.

Having established HDL as the location, the equipment selection process changed HDL has existing shop facilities that are used for fabricating prototypes and specialized equipment for fabricating prototype subassemblies of some electronic fuze components These facilities were first examined to identify areas that differed from current and anticipated industrial practices Equipment selection now emphasized these areas where differences occurred. New areas were also included This approach was used to minimize capital investment while still providing the functional capabilities necessary for a PVF.

The additional equipment required by the PVF necessitated expansion of the current floor space in the Research and Engineering Building. This expansion had been part of the long-range construction plans at the new facilities at Adelphi, MD. The initial plan was formulated in April 1975 In May 1975, this plan was reviewed by top management at HDL and rejected Top management directed the development of a three-year project plan with military construction in the second and third years. Also specified was the selection of one element of the PVF for first-year funding Thick film hybrid circuit fabrication was selected, and a formal request for funding was made. This complete plan was presented and the first year element rejected at the FY77 Apportionment Hearings at the Armament Research and Development Command. Concurrently, management at HDL deferred the Military Construction Army (MCA) one year.

These deferrals caused a reevaluation of the three-year plan At the same time, the individual chapters were submitted and more detailed and accurate information was available on equipment, space requirements, and operations All this information was reviewed and analyzed The result of this was the formulation of a five-year plan for equipment purchase with construction occurring in the second and third years.

In developing this plan, several criteria were used in selecting the year of purchase. The importance of need was the governing selection criteria All the technologies and equipment selected are deemed necessary for the successful operation of a PVF, but the immediate need for some and the economic benefits derived from them justify their earlier selection The best example of this type of module is the thick film hybrid (TFH) facilities. In examining the direction of fuzing technology, TFH is the newest and a major cost driver in new fuze procurement; because of this it was the first module selected Operating efficiency was considered next. First, operating efficiency was considered as defined by the normal flow of work in the PVF-component or subassembly fabrication, fuze assembly, testing, and support activity. Second, self sufficiency of the operating modules was consid-

ered. Since it is possible that some segments of the PVF facilities would be approved and not others, modules were selected so that equipment purchased would be beneficial and could be justified even though equipment for the complete facility was not obtained. Thus, each year's funding will provide a specific increase in the operation capabilities of the PVF. The second year MCA made space requirements a consideration when selecting modules for the first and second project years. Not only is space very limited at HDL, but also the type of space needed for PVF equipment is not generally available within the General Purpose Laboratory. Prerequisites for operating modules were considered, although, as stated above, termination of the project at the end of any funding year will not affect the capabilities acquired up to that point. The rotary tables scheduled for purchase in the second year are necessary for the electromechanical module and electronic test module. Therefore, the electromechanical module is a prerequisite for the electronic test module, however, failure to obtain the latter module will not negate use of the equipment in the electromechanical area. Delivery time for the equipment was only considered when it affected one of the other selection criteria. Since most of the equipment is standard commercial equipment, delivery time is typically very short.

Figure XII-1 shows the five-year plan as developed in FY77. The horizontal strips on the figure represent different modules of the PVF. In some cases, these strips are divided into submodules, as with the power supply module. Each submodule shown is self-sufficient and can function without subsequent year funding for equipment. Typically, a module extends for one year. The third year was an exception, and these funds were extended through the first quarter of the fourth year. This is proposed so that delivery of equipment coincides with the completion of the building. The MCA composes a second-floor addition to the Research and Engineering Support Building (203). The addition will provide approximately 40,000 ft² of additional space for the PVF.

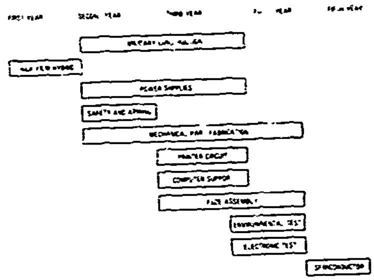


Figure XII-1. Five-year plan for Prototype Validation Facility.

This plan was acted on, and requests were submitted for the MCA and 55 percent of the equipment. The TFH equipment was still in the first year, but was also backed up by a second-year funding request under an alternative funding category. This was done because there was some concern during the first submission about the correctness of the funding category. The MCA was reviewed and approved by the Department of the Army. The Corps of Engineers was instructed to proceed with the final design in February 1977. The five-year plan suffered a major setback in May 1977, when the MCA was deferred one year. This caused another complete review of the plan because of the need to coordinate the equipment acquisition and the building construction.

As a result of reviews at HDL, it was decided that the earlier funding request for TFH equipment would be dropped and the back-up request used. Requests for printed circuit equipment and mechanical parts equipment would be deferred one year while some semiconductor equipment would be moved up one year.

With the MCA deferred another year, space requirements became critical in planning the ac-

quisition of equipment. It was decided that a shift of the whole five-year plan was not desirable. Instead, a four-year plan was developed. This plan is shown in figure XII-2. A shift to the four-year plan was possible because of the ongoing activities during the previous year. The major drawback to this plan was the high dollar value of equipment required in year four. This equipment includes items that have been under review. Although a final decision has not been made, it appears that approximately 25 percent of the fourth year equipment will be deleted. The major changes that are being considered are in mechanical parts fabrication, power supply assembly, and semiconductor fabrication. Funding requests have been prepared and submitted for equipment through year three. Funding requests for equipment in year four were prepared in March and April 1979 and were submitted by June 1979. The review of this equipment and a thorough analysis of the economics of its purchase were completed in March 1979.

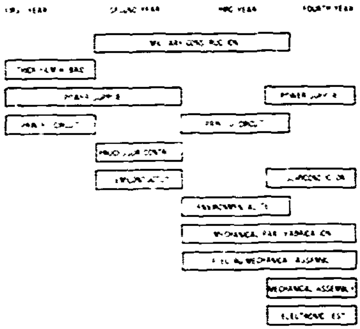


**Figure XII-2. Four-year plan for Prototype Validation Facility.**

The four-year plan represents current thinking at HDL, although the initiation date of this plan is in doubt because of the deferral of the MCA. This plan originated in 1975 as a two year plan and has evolved to the current four-year plan. Matching the acquisition of equipment to the building schedule was the primary reason for extending the years of equipment purchase. The desire to minimize the additional staff necessary for operating the PVF also contributed. By relying heavily on training of current personnel to operate the equipment, time had to be provided for this training. This training can be accomplished while continuing normal Model Shop Prototype Fabrication assignments during the four-year plan. Industrial equipment and processes will continue to be monitored by HDL, and if better equipment or processes become available, appropriate modifications will be made to the plan. Changes are not expected to be dramatic but because of the four years involved in purchase and the dynamics of the electronics fabrication industry some changes are anticipated.

Since the early planning of this project, the staffing and operating costs of the PVF have been a concern to all involved. The goal was to accomplish all work with existing staff. This goal was thought achievable by use of personnel in the Mechanical Engineering Support Branch and the Electronic Engineering Support Branch. These Branches fabricate the prototypes now, and would experience a decline in their workload with the PVF in operation. This establishment of a "part-time" labor force to operate the equipment removes the burden of down-time expenses from the PVF. The fluctuating nature of R&D work will invariably cause periods of relative inactivity and peak work periods. With proper scheduling, these periods can be balanced with other demands for similar services at HDL. Because of the planning necessary in scheduling work and the amount of equipment to be maintained, it is necessary to have a small permanent staff. It is felt that the scheduling and maintenance of the PVF can be accomplished by six people, two professionals and four technicians. These people would not represent an increase in personnel at HDL. They would be transferred from other areas of the organization and permanently attached to the PVF. The two professionals would include a mechanical engineer and an electronic engineer. The four technicians' duties would be equally divided between setup and maintenance. The exact responsibilities would vary, depending on the background of the individual.

## Chapter XIII.—Summary and Conclusions

by Harry E. Hill, Jr., and John J Furlani

The stated principal objective of this study was the definition of a facility that could manufacture and test prototype electronic fuzes using advanced state-of-the-art production techniques This objective has been realized The technologies and equipment necessary to apply them have been enumerated, the facility has been laid out in detail, and a multi-year plan for implementation of the findings of this study has been developed.

This study is the joint effort of nine branches at HDL. The distribution of work was recommended by a Steering Committee that convened to review this project The committee decided that the project should be managed by the Engineering Support Branch and that tasks related to specific component areas would be delegated to the appropriate branches within HDL. It was felt that this method would provide for the broadest input to the project within HDL at the lowest cost. The initial reaction of several branches to the prototype validation facility (PVF) concept was skepticism. Skeptical or not, they began to examine how they were doing things, what industry was doing, the costs of changing designs after testing, and problems that now occur in the manufacturing of electronic fuzes Attitudes gradually changed, and skeptics became advocates. The conversions first occurred within each area of expertise and gradually expanded into overlapping areas. Not all technical groups support the need for the complete facility. This is primarily because the problems peculiar to one area are not understood by those in other disciplines It is the consensus of those involved that the evolved plan should be implemented and that all elements should be included

The prototype validation facility represents a reemphasis of production aspects during development This had been considered during development, but the PVF now provides the tools for verification of producibility Not only will the tools be provided, but the development personnel will be actively involved, allowing them to benefit from this experience. Knowledge gained during prototype fabrication will be used to aid the management of contractors' efforts during development and later during the production phase Further, production techniques specific to a particular design will be passed along to the contractor to reduce transition time from development to production

The semiconductor research and development (R&D) personnel at HDL have been producing devices for electronic fuzes, radars, and optical systems for many years. They have been innovators in semiconductor technology, for example, they developed the two-step reduction process for mask making and the use of the step-and-repeat camera for generating large arrays. Much of their current work is directed toward the development of radiation-hardened semiconductor devices for military use. The trends developing in this area are the increased use of silicon monolithic devices and the integration of fuze functions The emphasis will be on bipolar and complementary metal-oxide semiconductors. The facilities proposed will allow for a practical transition between demonstrating feasibility and ensuring producibility. The area will have precise environmental control to minimize contamination, an ion-implanter for the accurate placement of impurities, injection-molded plastics encapsulating for lower costs, and semiautomatic equipment for process control

The electromechanical experts identified two separate areas where improvements are required. The first area identified was the support area of mechanical parts fabrication The use of low-cost fabrication techniques such as stamping, coining, casting, sintering, and molding is desirable in many electromechanical components, including S&A devices. These capabilities are necessary for component fabrication so that assembly and test operations will be performed on similar items Because of stringent safety requirements, extensive testing is required of S&A mechanisms, and process changes often require the repetition of these tests. The sec-

ond area identified was mechanized assembly, testing, and inspection This is integral to the design of the mechanisms and has the potential of large savings Currently, these are labor-intensive areas and the work is done by hand The emphasis will be on mechanization and merging of the assembly and test operations Mechanization will also offer improved safety in the fabrication area

Thick film microelectronic fabrication and assembly is a technology recently applied to electronic fuze circuits. It is not only an emerging technology, but one that currently is expensive for military systems The increasing use of multifunction fuzes and the increasing interest in fuzing smaller munitions are causing the use of this technology more and more. Problems that need to be worked on in this area are (1) the print-and-fire parameters that allow the needed fine line conductor patterns and achieve minimal resistor trimming, (2) adoption of active resistor trimming, compatible with high production rates, (3) automatic wire bonding with a single visual alignment, and (4) development of low-cost packaging techniques for the ordnance environment

The printed wiring board fabrication area will allow for additive and subtractive board processing and multilayer board fabrication Printed wiring boards will continue to be used in electronic fuzes when space permits and in other applications because they are rugged and relatively inexpensive In addition, printed circuit board techniques are used in the fabrication of antennas and rf stripline circuitry This area will provide the capability for fabricating printed circuits in large arrays which reduce handling and are desirable with automatic insertion equipment New processes will also be introduced such as the additive process, which uses less copper and results in less waste, and multilayer board fabrication, which increases circuit density and allows printed circuit techniques to be used on more complex circuitry

The electronic board assembly area will emphasize machine insertion of components. The relatively low cost of printed circuit boards compared to thin and thick film circuit methods and the proven ruggedness of these subassemblies in the ordnance environment virtually assures their continued use. Modern hand assembly stations and machine insertion will both be used The high density of components in some electronic applications requires partial or complete hand assembly Whenever possible, machine insertion will be used to decrease hand labor requirements for these assemblies. The use of large array circuits for machine insertion, mass soldering, and automatic lead cutting all affect circuit topology. Circuits assembled in this facility will have demonstrated compatibility with all of these mass-production techniques.

Most of the research and development that extends the state of the art in power supplies for electronic fuzes is conducted by the Government Safety requirements, limited space, and the extended shelf life of electronic fuze power supplies make them unique. Four power supply types meet these requirements. liquid reserve, thermal reserve, turboalternator, and fluidic generator The technology base for these is highly specialized and radically different from the commercial battery industry. The power supply area is already heavily committed to prototype power supply fabrication The equipment that power supply personnel is proposing will augment what they already have with the emphasis on techniques and processes that are very close to or can be readily adapted to those used by commercial manufacturers In addition, materials will be evaluated for their suitability to satisfy performance criteria and for their adaptability in fabricating the required power supply

The goal of the environmental test area is to achieve accelerated conventional environmental tests. This is necessary so that the environmental testing can keep pace with the increased rates of mechanized assembly. If production rates increase, the current level of confidence can be maintained, and if production rates remain constant, the testing level of confidence can be increased. The high cost of field tests and the time delay between fabrication and field testing make accelerated environmental testing desirable. Field tests will not be eliminated, but accelerated environmental testing will provide a quick reaction screening of production units and

allow for early detection of faulty production units The PVF can provide prototypes that closely represent production items. This will result in improved correlation of test results to final field performance These efforts—combined with recent advances in the technology of simulated environmental testing—have the potential of replacing field testing, after initial correlation, with simulated environmental testing

The electronic test area is where the proper functioning of the fuze is validated Experience has shown that on-line testing of electronic fuzes (particularly the radiating type) is a critical factor in the production process Design and fabrication of such equipment has accompanied each fuze development with the specifications and often the equipment itself being given to the production contractor for inclusion on the production line Numerous measurement and inspection techniques already exist and are in use in automatic fabrication and assembly lines for commercial mechanical and electronic items Many of these methods are directly applicable to fuze manufacture and can be incorporated into an automatic line with a high degree of confidence Other aspects of fuze testing, however, particularly special conditions applying to radiating-type proximity fuzes, have no direct counterpart in high production items on the commercial market It is on the second type of testing that the prototype validation facility will concentrate. Recent advances in microprocessors and related automatic equipment have permitted an expanded and more sophisticated role for such equipment Mechanical handling, automatic cycling of tests, and marking of tested fuzes will be included Minicomputer control of the microprocessor-controlled test station will provide flexibility and real-time data acquisition.

The electronic assembly area examined two problems. the final assembly of electronic fuzes and methods of nonstandard fastening The relative merits of rotary or synchronous machines and nonsynchronous transfer machines were discussed in some detail in the chapter describing the Electromechanical Facility There it was concluded that rotary tables were better, but for final fuze assembly the nonsynchronous system is advantageous, and for this application such a system is proposed Two types of nonstandard fastening methods were proposed ultrasonic and laser This equipment will be used to support both the electromechanical and the power supply areas. Several ultrasonic bonders were proposed to provide the needed range of frequencies and power levels Two laser systems were also proposed a 200- to 500-W yttrium aluminum garnet (YAG) or ruby laser and a 1- to 5-kW $CO_2$ laser The ability of this type of equipment to concentrate on small areas minimizes the possibility of damaging other areas or components on the work piece Both technologies are being adopted by industry for high-rate quality production because of their controllability and a resultant low reject rate

The mechanical parts fabrication area will operate in support of the rest of the facility. The primary deficiencies cited by development groups were the lack of powdered metal and die-casting technology The addition of these capabilities accounts for most of the effort Special design considerations safety requirements, and physical properties of the parts require the use of production-like parts during development testing Because of the large inventory of equipment and extensive use of screw machine parts, two screw machines were specified. These parts are not the most desired, because of dependance on foreign equipment, but until proven alternatives are developed they will continue to be used in quantity in electromechanical devices The current numerically controlled machine tool and plastic molding equipment is considered necessary and sufficient for proper operation of the overall facility. A general shop and inspection area is also necessary to support the facility. These capabilities are also enumerated

There are a number of areas within the Prototype Validation Facility where computer support is required This support will be provided by a combination of minicomputers and intelligent terminals that will tie into existing computer facilities at HDL. Management will use these facilities for scheduling, inventory control, and costing information. Computer-aided design and manufacturing will be

coordinated with the NC equipment throughout the facility. Portable terminals will provide real-time data acquisition from operating equipment and on-line test setups. These data can then be analyzed and/or used as inputs to simulation programs. Since the PVF will have single pieces of equipment when the production facility may have many, the cost of end items in production will rely to some extent on the ability to simulate the proposed production facility on computers.

Once each of the areas was defined, the individual areas were integrated into one combined facility. This involved the removal of duplications and the addition of areas overlooked in the separate chapters. Figure XIII-1 shows the layout of the proposed facility. The proposed location to house the PVF is a second-floor addition to the Research and Engineering Building at the Harry Diamond Laboratories, Adelphi, MD. Chapter XII (Planning and Progress) describes the plan for the Prototype Validation Facility in detail, including the construction and a listing of necessary equipment.

Of real concern is the problem of maintaining the PVF capability when the work level is low. This problem was considered early in the study and was recognized as a critical factor in assessing the practicality of the PVF. It was concluded that if an element of the PVF required the permanent assignment of specialists for operation then it was not practical for inclusion. As a result, each of the several study groups was informed that they should approach the problem with the assumption that the PVF activity could be maintained with existing staff. Further, if specialized knowledge was required for the operation of certain types of equipment, it would be obtained by training and not by recruiting additional staff. This was considered to be a reasonable limitation since equipment already existed and was being used to fabricate prototypes. With additional training, existing staff could become proficient in the operation of the equipment required for the PVF. Further, since the emphasis was being placed on producibility, more prototypes would be fabricated on the new and less on the old equipment. Thus, the overall workload would not be significantly increased.

An economic analysis was made comparing the predicted costs of fuzes in production under the current system versus these costs with the Prototype Validation Facility in operation. This analysis was based on the assumption that the utilization of the PVF during development will provide a head start toward the later production phase. This was estimated to result in a 10-percent reduction in unit production cost. Over an 11-year period, 11 projects were considered. The details are included in a document titled Economic Analysis for the

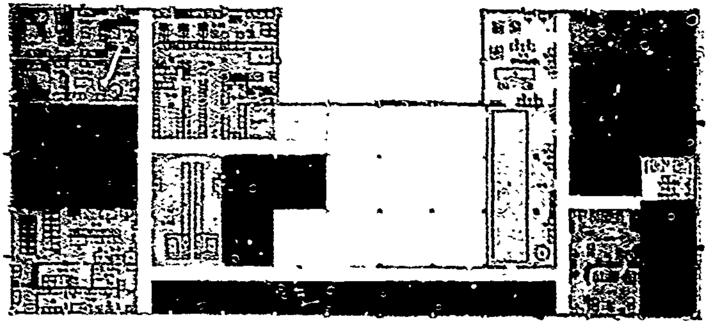


Figure XIII-1. Layout of proposed Prototype Validation Facility.

Research and Engineering Support Annex, July 1978 This analysis concluded that a total present value of savings amounted to 17 03 million dollars, a savings-to-investment ratio of 2 32 and a rate of return on investment of 22 percent These figures of course include the cost of construction, equipment purchase, and operating expenses

There is strong rationale to support the conclusion that a prototype design—using industrial-type fabrication methods made on production-like equipment that is validated by various test methods before release for production engineering—will present fewer problems and fewer scheduling delays, and will result in a cheaper, more reliable end product Computer support, on-line test data, and simulation testing will also provide documented test data packages against which later production-run units can be measured Because of the various production options, HDL personnel would be used efficiently by shifting people among the various areas as work loads change This will provide a group of people, well versed in the various production areas, that will be able to go to contractor plants, consult with and advise the contractor in setting up production lines pinpoint problem areas, and assist generally At least one individual will be responsible for overseeing and coordinating all operations, including value engineering, design-to-cost, quality assurance, reliability, and development of prototype test data packages Another individual will act as the library and conduit for collecting, staying abreast of, and disseminating state-of-the-art and technological advances relating to product engineering and automation The PVF group will form a reservoir of in-house expertise that will stay abreast of the latest advances in production technology areas pertinent to electronic devices, including fuzing They will thus be in a position to advise Army headquarters staff regarding electronic technology production, thus assuring a strong defense posture, complemented by mobilization readiness

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